

ECONOMIC GEOLOGY
OF
THE UNITED STATES



ECONOMIC GEOLOGY

OF THE

UNITED STATES

*WITH BRIEFER MENTION OF FOREIGN MINERAL
PRODUCTS*

BY

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P R E F A C E.

THE object in preparing this treatise is to supply the pressing need of a text-book to accompany a series of lectures given by the author to a class in Economic Geology at Cornell University. At first it was the intention to prepare merely a set of lecture notes ; but since this is at best a temporary and unsatisfactory expedient, and since the literature is so barren of works on this important subject, the author has decided to issue a text-book, with the hope that it may find a wider field than that for which it is primarily intended. It is a surprising fact that there is no text-book on Economic Geology which is sufficiently recent to be of value, and that nearly all of the books which have been issued on the subject treat exclusively of that part of economic geology which is in reality of least importance, and give no consideration to the large and important group of non-metallic minerals and rocks.

In the preparation of the book especial attention has been given to the mineral products of the United States ; and foreign localities are referred to only where they are of marked importance, or where they throw some light upon the origin of the materials. Even in this country only the most important and best known localities are described, types being chosen rather than large numbers of variable occurrence: and, throughout the various chapters, the prime object is to point out the geological aspect of the subject, and secondarily the economic importance

and relation of the several products. The scope of the work would need to be considerably enlarged to include much more than has been included here, and the expansion of the subject beyond this elementary outline must be left to the instructor. At times the treatment of the subject is somewhat dogmatic, since it is not possible, in such a small space, to always explain in detail the arguments upon which conclusions are based; but so far as possible this has been done. There is also some repetition; but this is intentional, and is introduced in order to illustrate the same principle from different standpoints.

Whenever possible, the localities chosen for description are those with which the author is personally familiar; but, in a field so broad, and covering so many diverse industries, it is scarcely possible for one person to possess information concerning all, or even a large proportion, of the typical occurrences, or even of all the industries. The work is, therefore, in many parts a compilation, and free use has been made of all available sources. This has sometimes amounted to an abstract of descriptions or conclusions, but rarely to actual quotations, since a more condensed statement than is usually found in such sources is needed here. The statistics are almost entirely compiled from the standard sources, and, where more detailed information is desired upon these subjects, reference may be made to these original sources.

Aside from the geological reports of the state and national geological surveys, and from special articles in the scientific journals, particularly the *Engineering and Mining Journal*, geological descriptions have been obtained from Phillips's *Ore Deposits* and the Census Reports. The purely statistical, and a considerable part of the economic portions of the treatise have been obtained from the annual reports of the Director of the

Mint; the reports upon the *Mineral Resources of the United States*, edited by Dr. D. T. Day under the auspices of the United States Geological Survey; the reports of the Census Bureau, particularly the volume on *Mineral Industries* in the reports of the Eleventh Census; and the *Mineral Industry, etc., for 1892*, edited by Mr. R. P. Rothwell, editor of the *Engineering and Mining Journal*. Particular acknowledgment is due the last-named work, since it contains a more valuable body of statistics and economic material, written by experts upon these subjects, than any other source; and, moreover, by the remarkable energy of its editor, the statistics are brought down to the close of 1892, and published a few months after its close. One will find there almost every variety of statistical and economic information upon the subjects treated. From these sources the statistics have been compiled, in some cases from one, in some from all combined, according as the needs of the work were best served. It has not seemed desirable to make direct acknowledgments in the following pages, excepting where some especial service can be rendered the student by direct reference to particularly valuable essays and monographs.

R. S. TARR.

ITHACA, N. Y., Sept. 5, 1893

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PART I.

INTRODUCTORY CHAPTERS.

ECONOMIC GEOLOGY

OF THE UNITED STATES.



CHAPTER I.

COMMON ROCK AND VEIN-FORMING MINERALS.

Elements and Minerals. — Chemical investigations have shown that about $\frac{99}{100}$ of the earth's crust is composed of the following sixteen elements: oxygen, silicon, aluminum, calcium, carbon, magnesium, potassium, sodium, iron, sulphur, hydrogen, chlorine, phosphorus, fluorine, manganese, and barium. About ninety-seven per cent of the earth's crust is composed of the first nine of these elements. Besides these there are over fifty other elements of greater or less rarity. Of the elements, oxygen is by far the most important. Nearly every element is found united with it, and in these various compounds it forms about one-half, by weight, of all the rocks. Silicon next in abundance, is always found united with oxygen.

Some of the elements occur in the earth's crust free from union with other elements. Graphite and diamond are pure carbon, and gold, silver, copper, and even iron, are also found

free or *native*. These native elements are, however, extremely rare when compared with the great mass of minerals. The crust of the earth is oxidized, and whatever may have been its original condition or what may be the condition of the interior, upon the surface nearly all of the elements are in chemical combinations of greater or less definiteness, and these are called *minerals*.

Minerals occur in the crust in several conditions. Typically they are *crystalline*, or with definite molecular structure, as in the igneous and metamorphic rocks and most mineral veins. Their structure may be *glassy* when formed by the rapid cooling of a lava, or *amorphous* (without form), as in flint, when precipitated, without crystallization, from solution. Any of these minerals, partly by decay, partly by mechanical destruction, may be removed from the parent rock and deposited as sedimentary or stratified rocks. The minerals are then *fragmental*, as in sandstones or shales. Some minerals are dissolved from the rock and later precipitated, as in the case of gypsum, or formed into a sedimentary rock by the intervention of calcareous secreting animals. In such cases the minerals are usually amorphous.

Theoretically, minerals have not only a definite chemical composition, but also a definite geometric form. The component molecules build themselves together according to definite laws; and when their growth is not interfered with, crystals are formed according to these laws, and the resulting crystal form is capable of mathematical calculation. Conditions which permit this perfect development are comparatively rare in nature, and consequently perfectly formed crystals are not common; but in most cases the tendency is shown by definite molecular structure with well-defined

optical characters. In mineralogy the crystallographic study is of prime importance,¹ but in an economic study of minerals it is less important than the chemical composition and the ever-present physical characters.

A few predominant chemical compounds make up the greater part of the earth's crust. Of these, silica (SiO_2), a combination of silicon and oxygen, is the most important. This forms quartz and its numerous varieties, amethyst, agate, flint, etc.; and, combined with other elements, often with an extremely complicated chemical composition, silica makes the great group of silicates, which includes the larger number of the common rock-forming minerals. Oxygen combined singly with an element forms another great group, the oxides to which many ores, such as those of iron, belong. Combined with aluminum oxygen forms alumina (Al_2O_3), a common mineral; and this combined with silica is the base of our clays and an important rock constituent. Oxygen with carbon and some other element forms the carbonates to which limestones belong; with sulphur and some other element it forms the sulphates (gypsum, etc.); and with phosphorus and another element the phosphates. Sulphur, without oxygen, combined with an element forms a sulphide, fluorine a fluoride, chlorine a chloride, etc.

The elements are divided into two groups, the metals and the metalloids. This division was made at a time when the known elements were fewer than at present, and was based upon the possession or absence of metallic characters; but it is now known that this division of elements is not as sharp as was at first supposed, though for the types of the two groups it still

¹ In Dana's works on mineralogy the subject of crystallography is treated, but the best work upon the subject is Williams' *Elements of Crystallography*.

holds. Of the sixteen elements above mentioned, oxygen, silicon, carbon, sulphur, hydrogen, chlorine, phosphorus, and fluorine are metalloids; the remaining eight are metals. Many of the metals are of economic value, because of certain properties which they possess; but the metalloids, excepting carbon and sulphur, are of little importance in the free state.

Nearly all common minerals, excepting quartz, contain metals in their composition, but the great majority have the metals either in such small quantities or in such refractory combinations that they are not separated. From the economic standpoint minerals are of importance in three distinct conditions. As rock-forming minerals, making a structure which can be utilized in the arts, some of the more common silicates are important. Secondly, certain minerals are of importance *as minerals*; the phosphates for fertilizers, the hydrocarbons for fuels and light, gypsum for plaster, and certain minerals which, because of rarity or beauty, are used as gems. Thirdly, many minerals are of value for the metal which they hold in chemical combination, and which man finds it profitable to extract. These three groups will be considered separately. In the first group are included quartz, feldspar, hornblende, augite, mica, calcite, and dolomite; in the second, carbon, sulphur, phosphate of lime, gypsum, salt, corundum, cobalt minerals, chromite, magnesite, talc, soapstone, and asbestos; in the third group, the ores and veinstones.¹

¹ This consideration of minerals is general, and should be supplemented by a study of the minerals themselves, preferably by a thorough course in mineralogy. The object in treating the minerals here is to give prominence to an aspect of the subject not usually found in text-books of mineralogy. The relations and characters of the rock-forming minerals are found in Rosenbusch's *Microscopical Physiography*, Vol. I. Translated by Iddings.

Common Rock-forming Minerals.— *Quartz* (SiO_2) occurs in many forms in the earth, being very variable in colour, but commonly either glassy, or clouded whitish or black, though frequently coloured, as in amethyst. It has a glassy lustre, is hard, scratching glass readily, and is not scratched by the knife. There is no cleavage, but the mineral breaks with a rounded conchoidal fracture like glass. The specific gravity is low. Being both hard and not easily destroyed chemically, it is a very durable mineral, and remains long after many of the associated minerals have been decayed. Ordinary acids do not attack it, but it is soluble in small quantities in water, particularly when the water is charged with organic acids or alkaline carbonates. Hence quartz is transported by the water which creeps through the earth and is deposited in veins, and as a cement to many siliceous rocks, sometimes transforming sandstones to compact quartz or quartzite. That it is present both in fresh and salt water is shown by the fact that certain plants (Diatoms) and animals (Infusoria) build their shells or tests of silica which they extract from the water. There is no mineral more common than quartz. Sandstones are made up almost entirely of quartz grains, the fragmental remnants of previously existing rocks which have disintegrated and given up their less durable minerals to form clay. Gneiss and schist, rocks derived by metamorphism from other rocks, are in part made up of quartz, which, in some cases, forms the bulk of the rock. The original condition of quartz, as in the case of a great majority of minerals, is in eruptive rocks. Certain of these rocks, notably the granites, rhyolites, and quartz porphyries, contain this mineral as an essential constituent, it being one of the two predominant minerals. Aside from these common occur-

rences quartz is found in less abundance in many other rocks, sometimes in large pieces, sometimes in minute and even microscopic grains.

Feldspar Group. — The group of feldspars is divided into many species, but it is necessary to recognize here only the two main subdivisions, — the *orthoclase*, or potassium group ($K_2OAl_2O_3SiO_2$), and the *plagioclase*, or lime soda group ($Na_2OCaAl_2O_3SiO_2$). Aside from the chemical basis for this division there is also a crystallographic difference, each group belonging to a different system. Both groups have certain characteristics in common. There are well-defined cleavages,¹ the specific gravity is low, and the hardness less than in quartz, but just beyond the touch of the ordinary knife. The colour is usually dull and whitish, from decay, though green and reddish colours are not uncommon, and some fresh feldspars are colourless and glassy. On the cleavage faces the lustre is pearly, but on the rough fracture it is glassy. They differ somewhat in their ability to decay, but all are destructible; and the different species, being of different chemical composition, decay at different rates. The chief difference, and the only one that can be made use of in the absence of a microscope, or a chemical analysis, provided the crystal form is not present, is the presence or absence of fine striations on one of the cleavage faces. These are very noticeable on some plagioclases, but never on orthoclase; but, as it is not universally present, it is not of much value, and hence in this statement but little stress can be placed upon the division of the feldspars. An acquaintance with the rocks usually serves to indicate this difference in the feld-

¹ A cleavage is a smooth fracture plane in a definite direction with reference to the crystal faces or the crystallographic axes.

spars, but this can only come after long experience in examining them. Feldspar, even in small grains, can usually be told from quartz by the presence of the smooth cleavage faces, and usually by the clouded, somewhat decayed appearance, contrasted with the fresh glassy appearance of the quartz.

The feldspars are extremely abundant and their distribution very widespread. In the igneous rocks they are more abundant than quartz, since in one form or another they appear in nearly all the common varieties. The feldspars are almost equally abundant in the metamorphic gneisses and schists. When attacked by weathering and percolating water, being chemically complex, they begin to decay and form simpler compounds. The salts of potassium, sodium, and calcium are transformed chiefly to soluble minerals which are carried away in solution, while the silica and alumina form quartz and kaolin, a hydrous silicate of alumina ($\text{H}_2\text{Al}_2\text{Si}_2\text{O}_8 + \text{H}_2\text{O}$), which is the chief constituent of many clays.

Amphibole Group. — To this group belong hornblende, which is the most common, tremolite, actinolite, and *Hornblende* is a silicate of magnesia with lime, iron, usually alumina, and a small percentage of other compounds. The colour varies in the amphiboles from black to white, but common hornblende is usually either black or dark green, the intensity of the colour varying with the per cent of iron and other metallic compounds. It is hard, heavier than either quartz or feldspar, has a glassy lustre, a conchoidal fracture, and a fairly perfect cleavage in two directions, with a pearly lustre on these faces. In granites, diorites, gneisses, and schists, it is common, and in many other rocks it occurs

in less abundance. Owing to the readiness with which it decays, it is rarely found in the sedimentary rocks, although the products of its destruction enter frequently into the clays and shales.

Pyroxene Group.—The only common mineral of this group is *augite*, which resembles hornblende very closely both in chemical composition and physical structure. Indeed, unless the crystal form or the cleavage can be seen, the two cannot be told apart in the rocks. Generally the *augite* is more greenish in colour than hornblende, but unless the two are seen side by side, this hardly serves to distinguish them. The cleavage of *augite* is nearly rectangular, while that of hornblende forms a much greater angle. *Augite* is much less abundant than hornblende, but in some of the lavas, such as basalt and diabase, as well as in some of the gneisses, it is the predominating mineral.

Mica Group.—Mica is a family name applied to a wide variety of species which, however, can be considered here under two general groups, the white or *muscovite* mica and the black or *biotite* mica. Both are silicates of alumina with iron, potassium, magnesium, sodium, and other elements in smaller quantities. The white mica contains little iron, while the black mica sometimes carries as much as twenty-eight per cent, the intensity of the blackness being usually proportional to the amount of iron. The true *muscovite* is very nearly transparent, while the extremely black *biotite* barely allows light to pass through thin flakes. In specific gravity they are about as heavy as hornblende, but there is some difference among them, the very ferruginous micas being a little heavier than the *muscovite*. They resemble each other in hardness (being easily scratched with the knife), in their

pearly lustre, but primarily in their remarkable cleavage, which allows them to be split readily into extremely thin, elastic plates. When occurring in fine grains, as in granites, it is sometimes difficult to distinguish the black mica from hornblende; but the remarkable cleavage is easily recognized, and this serves as a distinguishing feature.

In the rocks mica is perhaps most abundant in the schists and gneisses, though it is present also in many granites as an essential constituent, and also in other igneous rocks as an essential or accessory mineral. The white mica does not decay readily, and is consequently present in many sandstones. Biotite is also present in some of the sedimentary rocks, but it usually decays by the loss of iron and some of the soluble salts, and the absorption of water. *Chlorite* is then formed, and this mineral is found in clays and other sedimentary rocks often in great abundance. It is present in some schists, giving to them, as also to the clays, a greenish colour. It can be distinguished from anhydrous mica by its green colour and the marked cleavage, forming flakes which are no longer elastic.

Calcite (CaCO_3) is commonly either colourless or white, as in white marbles, though various colours are sometimes assumed. It is soft, of low specific gravity, and can be told from other common minerals by its action upon the application of dilute hydrochloric acid, when a brisk effervescence is caused. In the rocks it occurs, as a very widespread constituent, in minute quantities, in many igneous, metamorphic, and sedimentary rocks, but as the main constituent of limestone and its metamorphosed product, marble. In these strata it is usually impure by admixture of clay or some foreign minerals which give various colours to the rock.

Dolomite.—Not uncommonly the carbonate of lime is combined chemically with magnesium, and the resulting mineral is dolomite ($[Ca, Mg]CO_3$). This resembles calcite very closely, but does not effervesce with weak, cold acids, though it will effervesce when the acid is heated. There are many dolomitic limestones, but in other rocks the mineral is uncommon. Both dolomite and limestone are used not only for building-stones, but also for a source of lime, and as a fertilizer.

The above minerals constitute the greater part of the rocks of the earth's crust. The only other really abundant minerals are the ores of iron which are scattered through all rocks as well as gathered together into veins. Sandstone is practically all quartz, or quartz and kaolin; limestone and marble are either dolomite or calcite, and shales and clays are practically all composed of the decayed products, or finely ground fragments of some of the above minerals. Granite and the metamorphic gneisses and schists are composed chiefly of quartz and feldspar with either hornblende, mica, or augite, or a combination of these. The other igneous rocks are chiefly composed of feldspar, with hornblende, mica, or augite, or a combination of two or all three of these minerals. They are the essential minerals of the earth's crust, and other minerals are accessories, although in some rocks a rarer mineral may be in such quantities as to be an essential constituent of these particular rocks. For instance, a basalt may have enough olivine to become an olivine basalt, or a schist may be a tourmaline, epidote, or talc schist when one of these minerals is abundant; but for our purposes the rarer kinds of rock-forming minerals may be neglected.

Useful Minerals.—This group, which includes those individual minerals used without chemical change, is a very large one, but only a few will be described. There are many rare minerals, such as the gems belonging to this class, but it is hardly necessary to describe these here.

Carbon Group.—The minerals belonging to this group are of three distinct kinds,—(1) the organic material of indefinite composition stored in the earth and in places transformed to coal or mineral oils, (2) graphite, and (3) diamond. Coal is not properly a mineral; at least, it is not strictly the element carbon, but rather a hydrocarbon consisting of a great variety of chemical and mechanical mixtures. Y.^{et} from the stage of pure wood there is every gradation to graphite, through peat, lignite, bituminous coal, anthracite, and graphitic anthracite. Allied to this group is asphaltum, which in turn grades to mineral oils, and these to various indefinite carbonaceous compounds stored in the rocks. Carbon in these forms exists not only in beds and other accumulations, but also disseminated through many of the stratified rocks, particularly shales and limestones, where the black colour is often due to these hydrocarbons derived from the remains of animals or plants fossilized in the rock. With the hydrocarbon there is frequently some pure carbon.

When rocks are altered by heat, or by folding with accompanying heat, these carbonaceous substances are slowly transformed, in many cases, to fixed carbon, or *graphite*. Thus in metamorphic rocks, which are the result of the alteration of sedimentary strata, graphite is common in flakes and often in veins. Among marbles this is a common phenomenon. Aside from these occurrences graphite is found both in flakes and in veins in rocks which are not so cer-

tainly of sedimentary origin, and here its occurrence is not so easily explained. Graphite is a dead black mineral with a dull metallic lustre, a greasy "feel," and a hardness so low that it soils the fingers.

Diamond, the other form of fixed carbon, is, when pure, perfectly colourless, with an extremely brilliant lustre and a hardness greater than that of any other mineral. Its origin is not definitely known, but it seems probable that it is the result of a very slow metamorphism of some previous condition of disseminated hydrocarbon.

Sulphur is found in the earth not only in combination with other elements, but also native, sometimes the result of solfataric action near volcanoes, but frequently the product of disintegration of some sulphate or sulphide. It is usually yellow, soft, brittle, of low specific gravity, and with a resinous lustre.

Phosphate of lime is usually the result of animal accumulations. The bone beds and guano deposits are directly of this origin, but are impure both by chemical and mechanical combinations. Phosphatic matter is found not only in considerable accumulations, but also disseminated through the sedimentary rocks, so that when these are metamorphosed, the *mineral phosphate*, *apatite* ($\text{Ca}_3\text{P}_2\text{O}_8$ with some chlorine or fluorine), is produced. Not only is it found in places where its origin seems organic, but also as an accessory mineral, in scattered crystals in many truly igneous rocks as well as in massive gneisses. In the latter it is sometimes found also in veins. Apatite is of medium specific gravity, it can be scratched with a knife, its colour is variable, though most commonly greenish, and its lustre is vitreous. Only when found in veins is it of economic

importance, though its presence in the rocks adds to the value of the soil resulting from their disintegration.

Gypsum, the sulphate of lime ($\text{CaSO}_4 + \text{water}$) is easily scratched with the knife, has a marked cleavage with a pearly lustre, and is usually white in colour. It is present in solution in most water, giving to it the property known as "hardness." In the ocean gypsum exists in solution, and consequently sedimentary rocks of marine origin have this mineral disseminated through them. By the evaporation of salt lakes gypsum becomes concentrated as does salt, and it is frequently precipitated in beds when these bodies of water are destroyed by desiccation. Limestone beds are at times transformed to gypsum by the accession of sulphur carried in solution from some source, frequently the decay of sulphides or sulphates; and, by a similar process, gypsum is sometimes formed about sulphur springs and volcanoes.

Salt is present in many rocks, particularly those of sedimentary origin, and it is derived from the decay of rocks by the union of chlorine and sodium. As a mineral it is usually formed in the earth by precipitation from a dead sea, though much of the salt supply comes from a brine which is present in sandstones of certain ages.

Corundum (Al_2O_3), when pure, bears a marked resemblance to quartz, but it can be distinguished from this by its cleavage and excessive hardness, being next, in the scale of hardness, to diamond. The two pure forms of this mineral, corundum and sapphire, are comparatively rare; but emery, a black variety coloured by iron impurities, is more common, occurring in veins in metamorphic rocks.

Cobalt Minerals.—The two most important ores of cobalt are smaltite and cobaltite. *Smaltite* is a combination of

arsenic with cobalt, iron, and nickel in varying quantities. It is tin-white or steel-gray, sometimes iridescent from tarnish, and has a metallic lustre. It is not easily scratched with a knife, and has a high specific gravity. *Cobaltite* (CoAsS) is silver-white in colour, with a red tinge and a metallic lustre. When, as is sometimes the case, a part of the cobalt is replaced by iron, its colour is grayish black. There is sometimes present on the cobalt ores a peculiar apple-green rust, *annabergite*. These minerals are the source of the cobalt compounds in the arts.

Chromite, or chrome iron ore (FeCr_2O_4), is the source of chromium oxide and the compounds of chromium in use in the arts. Its colour is between iron-black and brown-black, with a submetallic lustre. It can be scratched with the knife with difficulty, and is of moderately high specific gravity. The verd antique marble owes its colour partly to this ore.

Magnesite.—This comparatively rare mineral is found in considerable abundance in California. It is closely allied to dolomite, the latter being $\text{CaMg}(\text{CO}_3)_2$, whereas magnesite is simply carbonate of magnesium (MgCO_3) without lime. It is a brittle mineral of moderate hardness, being scratched with the knife, and in colour varies from white to brown, and from transparent to translucent.

Talc ($\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$) is a soft mineral with a soapy feeling and a greasy lustre, and a colour varying usually from green to grayish white. The lustre is pearly on the cleavage faces, and the cleavage is well developed, so that the mineral splits easily into thin laminæ, but these are not elastic as in micas. *Soapstone* is a variety of this, usually more or less impure. These minerals occur very commonly in meta-

morphic rocks, particularly in the less gneissic schists, where talcose slates and schists are abundant.

Asbestos.—Two very different minerals are included under this name in commerce, owing to their common fibrous nature. One, the true mineralogical asbestos, is one of the amphiboles and is allied to actinolite, of which it is one variety. Chemically, it is a silicate of lime, magnesia, and iron ($\text{Ca}[\text{MgFe}]_3\text{Si}_4\text{O}_{12}$). It crystallizes in fibres which are capable of being woven into a fire-proof cloth, the amianthus of the Greeks. The second form of asbestos is *chrysotile*, a fibrous variety of serpentine ($\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9$). It has a silky lustre, and usually a greenish white colour, and has nearly the same properties as true asbestos.

To these might be added calcite and dolomite (described above), since they are used in the manufacture of lime and for a fertilizer, serpentine, and the various gems, as well as the veinstones, fluorite and barite.¹

Common Vein-Forming Minerals and Ores.—*Character of Ores*. The ores, though of so much importance from the standpoint of economic geology, are, with the exception of those of iron, comparatively rare. An ore may be defined as a mineral with a metallic base. It may be a native metal, or it may consist of two parts, a metal and a mineralizer, which may be a single element (usually a metalloid) or several elements. Properly speaking, the metallic constituent should be a predominant constituent. For instance, biotite, which contains iron, is not an ore, because the metal is in such small quantities. The miner considers an ore to be a mineral with a metallic base, occurring in sufficient abundance to be economically valuable but, from the scientific standpoint, a grain of

¹ See p. 17.

magnetite in a granite rock is as much an ore as a bed of this mineral.

According to the mineralizer, or the chemical composition of an ore, we have a basis for the classification of ores, and, indeed, of all minerals. Some elements occur native; that is, free from combination with metalloids. Such are copper, gold, silver, platinum, and others; but these may occur mechanically mixed or in alloy with one another. Platinum is found in this way commonly associated with osmium and iridium, while native gold is nearly always alloyed with silver.

The metal may be combined with sulphur or with some rarer element (arsenic, tellurium, antimony, bismuth, etc.), when it is known as a sulphide, arsenide, etc., of the metal. When combined with chlorine, bromine, iodine, or fluorine, a chloride, bromide, iodide, or fluoride is formed. An extremely common group of ores is that of the oxides, where oxygen in different proportions is united with the metal, and there may be several oxides of the same element. These, as in the case of many other compounds, may be hydrous or anhydrous, according as they have water in combination or not. When a metal is combined with silica (SiO_2), a silicate is formed. The group of silicates is extremely large, including many of the important rock-forming minerals, but as ores they are of little importance. Most of the silicates are extremely complex (hornblende, mica, feldspar, etc.), forming the group of bisilicates, but the few ores in this group are unisilicates, or minerals where only one metal is combined with the silica. When sulphur is in the place of silicon (SO_3 instead of SiO_2), the sulphates are formed, and when in place of this there is carbon (CO_2), carbonates result. Aside from

these there are certain rarer compounds, the phosphates, arsenates, borates, etc., which are of little importance as ores.

Common Veinstones. — Ores considered from the economic standpoint occur in beds or in veins. Usually they are associated mechanically with other minerals, sometimes rocks, which are of no economic value, and are known as *gangue* or *veinstone*. Almost any mineral may occur as gangue, and frequently there are several, some of which may be ores, such as iron pyrite, which are not of economic value. The most common veinstones are quartz, calcite,¹ fluorite or fluor-spar, and barite or heavy-spar, the first two being by far the most common. Many rarer minerals also occur as a part of the gangue in mineral veins, and it is from these places that many of the cabinet specimens of minerals are obtained.

Fluorite (CaF_2) resembles calcite somewhat, being usually white, or transparent, though often coloured, having a very perfect cleavage and a vitreous lustre. It is, however, harder and somewhat heavier than calcite, and does not effervesce with acids, so that it is easily distinguished.

Barite (BaSO_4) has nearly the same characters as fluorite, but is strikingly heavy for a light coloured mineral, and one is attracted by its weight; hence its name heavy-spar. This mineral, as well as the others, has a distinctive crystal form; but, since it occurs more commonly as a massive mineral, this character is usually not of importance.

Common Ores. — Through these veinstones the ores are distributed, sometimes uniformly, sometimes very irregularly. At times they are concentrated into layers, often they are disseminated. In one part of the vein the ore may be of one chemical combination, in another a different kind may be

¹ Quartz is described on p. 5, calcite on p. 9.

found; and even different metallic bases may predominate in different parts of the vein.

One of two methods may be adopted in a classification of the different ores, — the mineralogical, based upon chemical composition, or what may be called the economic, in which the basis of primary division is the metal which the minerals contain. The latter is adopted here, as in the later chapters, for the general groups; and under each metal the different mineralogical occurrences of importance are mentioned for the following: iron, gold, platinum, silver, copper, lead, zinc, mercury, manganese, aluminum, tin, nickel, and antimony. The ores of cobalt and chromium are omitted here since they are not used as a source for the metal, but as minerals, and hence are considered under the previous group. The specific gravity of nearly all the ores is high, and will not be given unless it is exceptional.

Iron occurs, as an ore, in a number of mineralogical associations, but chiefly in the form of an oxide. Native iron exists in meteorites, and also in Greenland in an eruptive basalt, but in none of these occurrences is it valuable as an ore. The ores of iron are usually marked near the surface by the yellow iron rust with which we are familiar in old iron.

Iron pyrite, the sulphide of iron (FeS_2), is mined for the sulphur, not for the iron it contains, the combination being so refractory that all the sulphur cannot be removed without great expense. It is brass-yellow in colour, with a metallic lustre, and is too hard to be scratched with a knife. It grades into copper pyrite, but when there is much copper present the colour becomes more golden. Sometimes, though not commonly, gold occurs in iron pyrites in in-

visible grains. There are other forms of pyrite in which iron is a constituent with some other metal, but none are so common as the almost pure iron pyrite.

Limonite ($2\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$), hydrous sesquioxide of iron, is a brown or yellow mineral sometimes very earthy, but in its pure form having a hardness about equal to that of steel. A number of mineralogical varieties are commonly included under this mineral, the entire series of hydrous sesquioxides of iron (including göthite, turgite, bog iron ore, etc.) being called brown hematite by miners. The series can be told from other ores of iron by the fact that their powder is yellow or yellowish brown, and this is best seen by testing the "streak" which is obtained by scratching the mineral on a piece of rough porcelain or white quartz.

Hematite (Fe_2O_3) differs chemically from limonite by the absence of water, and there is accordingly every gradation between the two, the rust of hematite being limonite. The red colour of soils is due to a hematitic iron, as the yellow colour is to limonitic iron. Hematite is harder than limonite, has a metallic lustre, and varies in colour from red to brown, or even black. Its streak is reddish brown, and it serves to distinguish it from limonite and magnetite, the streak in the latter mineral being black. There are four common varieties of this species, — (1) *specular hematite*, which has a brilliant metallic lustre, and which is called micaceous hematite when the structure is foliated; (2) *columnar hematite*, where the structure is radiating and the lustre less metallic; (3) *red ochreous hematite*, where the colour is red and the structure earthy; and (4) *argillaceous hematite* (clay iron stone), when the earthy form is mixed with clay. Miners include under the name red hematite all those vari-

eties having a red streak, and according to the form of the ore they give different names, such as flaxseed ore, fossil ore, etc.

Magnetite (Fe_3O_4) is always black, with a black streak, a metallic lustre, usually with a granular structure and conchoidal fracture. In hardness it cannot be scratched with the knife. A feature which distinguishes it from the other ores of iron is its magnetic property.

Franklinite is almost identical in form and appearance with magnetite, but it is not magnetic, and differs chemically in the possession of both zinc and manganese in addition to iron. In this country it occurs in only one locality as an ore, and that is at and near Franklin Furnace, Sussex County, New Jersey.

Siderite, the carbonate of iron (FeCO_3), is readily scratched with the knife, is light compared with other iron ores, and in colour varies from gray to brown. It very closely resembles a discoloured calcite, which in reality it frequently is, the calcium being replaced by a certain per cent of iron, and in pure siderite being completely replaced.

Gold occurs in the earth in only two mineralogical forms, so far as known, one in association with tellurium, the other native, the latter being its typical occurrence and the one from which the gold in use is obtained. While we speak of it as a native ore, this is not strictly true, since gold is nearly always alloyed with other metals, chiefly silver, in greater or less proportions. It is found mixed mechanically with other minerals such as iron pyrite, copper pyrite, and silver ores, and much of the gold is obtained from the last two sources, being a by-product in the extraction of the other metals.



Platinum occurs as an ore in the native form, but, like gold, usually alloyed with other metals, chiefly iron, iridium, and osmium. It is found in irregular lumps, usually of small size, is steel-gray in colour, has a metallic lustre, can be scratched with the knife, and has an extremely high specific gravity.

Silver is found in much greater variety of chemical combinations than the two last metals, since it is much more readily attacked by the ordinary mineralizers. Native silver is less common than the mineralized species, but it is, nevertheless, not uncommon. It also occurs native as an alloy of gold, copper, and other metals, and much silver is annually obtained from these sources. A large part of the supply of silver of this country comes from the sulphide of lead, where silver at times replaces some of the lead. There are numerous ores of silver, but only three are of marked importance.

Argentite (Ag_2S) is a blackish lead-gray mineral with metallic lustre, and distinguishable from the other ores of silver by its malleability. The argentiferous lead sulphide may be considered a mixture of this mineral and lead sulphide, the richness in silver varying with the proportion of argentite.

Pyrargyrite, or ruby silver, is a sulphide of silver with antimony and sometimes arsenic. Its colour is black, sometimes a very deep red, and always with a ruby-red streak. The lustre is very brilliant metallic.

Cerargyrite, or horn silver (AgCl) is extremely soft, and can be cut with a knife like horn. The colour is usually gray, and the lustre resinous. With a very low heat the chlorine is driven off and native silver left. This ore is

found in the Cordilleras, Mexico, and South America, in the latter place, particularly in Chili, occurring with a bromide and iodide of silver.

Copper is found native in this country chiefly in the Lake Superior region. Its most common occurrence, however, is as the sulphide, *chalcopyrite* (CuFeS_2), or copper pyrites, which is in reality a sulphide of iron and copper combined, the proportion varying from an exceedingly cupriferous variety (chalcopyrite) to pure iron pyrites. The former is golden yellow in colour with commonly an iridescent tarnish; the latter is brassy. Another sulphide, *chalcocite* (Cu_2S), is lead-gray and rather soft. The oxide *cuprite* (Cu_2O) is red in colour and translucent, with a metallic lustre, sometimes brilliant, sometimes earthy. *Chrysocolla*, the silicate ($\text{CuSiO}_3 + \text{water}$) is green to bluish green, the colour of copper rust. The lustre is vitreous, the specific gravity low, and the mineral soft. There are two carbonates of copper, — *malachite* ($\text{Cu}_2\text{CO}_3 + \text{water}$) and *azurite* ($\text{Cu}_3\text{C}_2\text{O}_7 + \text{water}$), — the first being green in colour, the second blue, and each with brilliant vitreous lustre, of low specific gravity, and with a hardness such as to admit of its being easily scratched with the knife. Ores of copper are usually more or less oxidized at the surface, and can generally be told in such places by the characteristic green or blue rust.

Lead does not occur native, but is most commonly found in the sulphide *galenite*, or galena (PbS), a lead-gray mineral, with a metallic lustre and well-defined cleavages. The knife scratches it easily. Galena is very commonly argentiferous, and a considerable percentage of our silver is extracted from this ore. The sulphate of lead, *anglesite* (PbSO_4), is white, yellowish, or grayish, soft, and has a resinous lustre.

Cerussite, the carbonate (PbCO_3), has usually a white or grayish colour with a brilliant vitreous lustre, and is easily scratched with the knife. Both the sulphate and the carbonate are commonly the result of the decomposition of some other form of lead ore, usually galena, and all of the lead ores are frequently marked at the surface by a peculiar pale yellow rust.

Zinc occurs most commonly as zinc blende, or *sphalerite*, a sulphide (ZnS), called by miners black jack. It varies markedly in colour, but is most frequently brown or yellow; it has a peculiar resinous lustre which is quite distinctive; it can be scratched with a knife, is rather light for an ore, and has very marked cleavage. There are two oxides of zinc, *franklinite* (already described under iron) and the red oxide of zinc, *zincite* (ZnO), which has a red colour, usually of a deep shade, though sometimes being orange-yellow, a brilliant vitreous lustre, and a hardness within the touch of the knife. Zinc as an ore occurs as a silicate in two forms, the hydrous and the anhydrous. The latter, *willemite* (Zn_2SiO_4), is usually yellow with a vitreo-resinous lustre and a conchoidal fracture. As in most silicates, the specific gravity is low for an ore. The hardness is not great. *Calamine*, the hydrous silicate ($\text{Zn}_2\text{SiO}_4 + \text{water}$), is white in colour, but otherwise resembles willemite, excepting that it is lighter on account of the contained water. *Smithsonite*, the carbonate (ZnCO_3), is usually white or grayish, with a vitreous lustre inclining to pearly, and a hardness and specific gravity about like that of willemite. It effervesces with acids, as do many of the carbonates. All of the above ores of zinc, with the exception of franklinite, are translucent, or in some pure specimens transparent. A

whitish rust is frequently present in zinc ores which have been exposed to the action of weathering.

Mercury occurs as an ore in the form of the sulphide *cinnabar* (HgS), although sometimes native mercury is formed by the decomposition of this ore, the affinity of the two elements being very slight. Cinnabar is very soft and heavy, has a brilliant lustre, is red in colour, often of a deep shade, and breaks with an uneven fracture. When heated carefully, the sulphur is driven off and metallic mercury is left; but if heated too high, both the mercury and sulphur disappear. This ore is used not only as a source of metallic mercury, but also as a mineral for vermilion.

Manganese occurs in many rocks as a black or purple stain, and it is an oxide of this metal which forms the arborescent stains called dendrites, which are so common on cleavage and jointed faces in many rocks. It is found very commonly with iron in greater or less quantities; and, as it is in iron-working that the chief supply of manganese is used, much of the metal is mined in this form and never separated. There are, however, several ores which are mined for manganese, the principal being the three oxides,—pyrolusite, psilomelane, and wad. *Pyrolusite* (MnO_2) is usually black or dark steel-gray, with a metallic lustre, rather soft, and not very heavy. *Psilomelane* is a mineral of doubtful composition, being essentially an oxide of manganese and barium with water. Its characters are almost exactly like those pyrolusite, but it is much harder, and the knife scratches it with difficulty. *Wad*, or bog manganese ($\text{MnO}_2 + \text{water}$), is usually impure, just as is the case with bog iron ore and for the same reason. It is extremely soft and earthy, not heavy, and varies in colour from dull black

to bluish or brownish black. The ores of manganese usually rust to this mineral under the action of weathering.

Aluminum, although one of the most abundant of the metals, is also one of the most difficult minerals to extract from most of its ores, since it is firmly held in chemical combination by its mineralizers. It is found in all the silicates of alumina, of which there are many, and is present in all feldspars and in the clay or kaolin which results from their decay. Ordinary *kaolin* ($\text{H}_2\text{Al}_2\text{Si}_2\text{O}_8 + \text{water}$) contains an inexhaustible supply of this metal, but it cannot at present be economically extracted. *Corundum* (Al_2O_3) is a possible source of aluminum, but is not now used, because it is more valuable for other purposes. *Cryolite* ($\text{Na}_6\text{Al}_2\text{F}_{12}$) is one of the chief sources of aluminum. It is usually pure white, though sometimes coloured, has a vitreous lustre, is translucent, brittle, easily scratched with the knife, and has a rather low specific gravity. It is fusible in the flame of a candle. The mineral *bauxite* (or *beauxite*) ($\text{Al}_2\text{O}_3 + \text{iron and water}$), also used as a source of aluminum, is white or brown in colour, and occurs as concretions in clay. The colour and hardness vary with the per cent of iron. It is a comparatively light mineral.

Tin is obtained entirely from the oxide *cassiterite* (SnO_2), which is usually brown or black, with a brilliant lustre, a hardness too great to be scratched with a knife, and a high specific gravity. With the blowpipe, it can be reduced on charcoal with soda to metallic tin. The ore is found both as *tinstone*, in coarse granites or pegmatites, and as *stream-tin*, in river gravels, where, by the decay and removal of the tin-bearing rock, it has accumulated, owing to its high specific gravity and chemical indestructibility.

Nickel is obtained from the two sulphides, millerite, niccoliferous pyrrhotite, and the arsenide niccolite. *Millerite* (NiS) is a brass-yellow mineral, usually with a gray iridescent tarnish, a metallic lustre, and a moderately high specific gravity. It is brittle and can be scratched with a knife. *Niccoliferous pyrrhotite* is a sulphide of iron (Fe_7S_8), with more or less nickel, and this ore is the principal source of nickel. In colour, it is bronze-yellow and copper-red, usually tarnished, and in specific gravity, hardness, and brittleness, it resembles millerite. In a fine powder it is attracted by the magnet. *Niccolite* (NiAs) is harder and heavier than either of the other two ores of nickel, being scarcely scratched with the knife. The colour is pale copper-red, with a gray or blackish tarnish, and a metallic lustre. Associated with nickel are the ores of cobalt,¹ and one of these ores, smaltite, contains nickel in varying proportions.

Antimony and its compounds are obtained from the mineral *stibnite* (Sb_2S_3), a soft, sectile mineral of medium specific gravity, a metallic lustre, and a lead or steel-gray colour, with a blackish or iridescent tarnish. It is soluble in hydrochloric acid.

The above summarized description of minerals gives only those tests which can be applied roughly in the field without the use of exact methods, and includes those features which are present in ores, omitting the more purely mineralogical characters. The object of the summary, however, is less the presentation of the mineralogical than the geological features. There are many other minerals which one is liable to encounter in the mines and quarries, some of them of economic value, but the above include the most common species, and

¹ Described above, p. 13.

the ores which are most liable to be met with frequently in economic work. Without a thorough mineralogical study, a more complete list or a more thorough statement of the features of the minerals would be useless; but such a study is very desirable, indeed necessary for one who wishes more than an elementary knowledge of economic geology.¹

¹The most complete text-book on mineralogy is Dana's *System of Mineralogy*, though the essential features are given in the *Text-Book* or the smaller *Manual of Mineralogy* by the same author. Brush's *Blowpipe Analysis* gives the blowpipe tests for minerals. While there are numerous other text-books, these are the standard works and best adapted to the needs of the American student.

CHAPTER II.

ROCKS OF THE EARTH'S CRUST.

THE earth's crust, so far as it has been exposed to view by the processes of erosion, or by mining operations, is found to be composed of rocks of different characters, but all alike in the fact that they are composed of minerals. Sometimes a rock is composed of one mineral, but more commonly several combine to make up the rock-structure. Not only do they differ widely in mineralogical composition, but they differ both in form and in origin, and upon the latter basis we divide the rocks into three groups — Sedimentary, Eruptive, and Metamorphic.

Sedimentary Rocks. — There is no single term which can properly be applied to those rocks which are neither eruptive nor metamorphic. The term *sedimentary*, strictly used, includes only those rocks which are formed as sediments, and excludes a large group of rocks subaërially formed. *Stratified* refers to those which are formed in strata or layers, but many metamorphic rocks are truly stratified; and, on the other hand, the glacial deposits are, in large part, neither sedimentary nor stratified. The terms *fragmental* or *clastic* might be used were it not for the fact that they exclude certain chemically deposited rocks, as well as those of organic origin, which are truly stratified. Of these several terms, *sedimentary* is, perhaps, the best general name, and in this treatise it will be used to include all rocks which do not fall into the other groups,

and the most important of which are both stratified and sedimentary. The material forming these rocks is of secondary origin, being derived either by mechanical or chemical means from pre-existing rocks.

According to the nature of the material composing these strata we have a basis for classification. A *conglomerate* is composed of pebbles rounded, generally by water action, and cemented by finer, usually sandy particles, and some chemically deposited mineral, such as calcite or iron oxide. The pebbly beaches are composed of material which might readily become consolidated into a hard conglomerate. When the pebbles are angular, as, for instance, when they have not been transported far from their source, the rock is a *breccia*. The name *fault breccia* is given to a similar aggregate of angular fragments found in a fault plane, and caused by the crushing of the rocks. As upon a beach there is every gradation from a mass of coarse pebbles to a fine-grained sand, so among the sedimentary rocks there is every gradation between conglomerates and *sandstones*. The particles composing the sandstone are usually quartz, for the reason that this is the most durable of common minerals, and outlasts both the chemical disintegration and the mechanical wear to which the less durable minerals succumb in the process of weathering and transportation. Sandstone grades into *clay rocks*, which are composed of the finer parts of rock decay and of mechanical destruction. When consolidated these may become *claystones*, or *shales* if they split easily in the direction of the bedding, and these may be sandy, or, on the other hand, of exceedingly fine grain. Since there are these gradations, it may be difficult to say whether a rock is a shale or a sandstone, and then it may be necessary to introduce

a compromise term, such as shaly or argillaceous sandstone, or sandy shale, according to the predominating constituent.

These rocks are deposited in water, and in all bodies of water they are now being formed. The rivers, lakes, and oceans are repositories of these various materials, which are derived from the waste of the land. Frost and the agents of weathering cause the rock to disintegrate, the wind and moving glaciers grind the material finer; rain, gathering into rills, rivulets, and powerful rivers, sweeps this material toward, and finally into, the sea. Here the waves and currents work it over, grind it finer, and assort it, transporting the finer particles out to sea and depositing the coarser fragments near the land. The waves beating upon the shore batter off other fragments which are placed with those furnished by weathering and river erosion, and these all go to make up the sedimentary deposits of the ocean. These fragmental rocks are furnished by the land waste, and their source may be other sedimentary, or eruptive, or metamorphic rocks.

Chemically Precipitated Rocks.—When rains fall upon the land, a part of the water sinks into the ground, while the remainder gathers into streams. The former, and to a slight extent the latter, takes from the rocks a certain store of soluble mineral which it carries away. In places, notably in inland seas, where this mineral matter becomes concentrated by evaporation, the water becomes overcharged, and is forced to precipitate some of the dissolved mineral. Carbonate of lime, particularly the magnesian carbonate, gypsum, and salt, are the chief deposits of this nature. In the neighbourhood of hot springs siliceous rocks and deposits of carbonate of lime may be precipitated; but this class of rocks, since they

are very local, is of scarcely any general importance in a consideration of the structure of the earth's crust.

Organic Rocks. — Far from land, where rock fragments are rarely transported, the ocean bottom receives practically nothing but contributions of organic remains, excepting such fragments as may be transported by ice, or such bits of pumice as may float to that point. Minute lime-secreting animals furnish the greater part of this supply, and, therefore, in great ocean depths there is a muddy ooze, composed principally of their tests or shells, and this is called *globigerina ooze*, from the predominance of species of animals belonging to this genus. The *chalk* of England is a deposit of very nearly this character. In still greater ocean depths, even this small supply is not furnished; for here, owing to the great pressure of the water, the lime composing these shells is dissolved as they drop toward the bottom. Here a *red ooze* is formed, which is composed of the insoluble residue, and is therefore of extremely slow growth. Among the surface rocks, we have as yet failed to identify any similar stratum.

Organic contributions to the strata are, however, more numerous than this. Practically, every sedimentary rock contains some relic of organic remains, even if no more than an indistinguishable powder of lime, resulting from the grinding up of calcareous shells. From this there is every gradation to pure *limestone*, when the entire stratum is made up of animal remains. Upon tropical coasts, where marine life attains a luxuriant development, there is frequently nothing furnished to the sea in solid form, excepting fragments of shells, corals, or other calcareous remains built up of carbonate of lime extracted from the sea-water by the

marine animals. Such conditions prevail in coral-reef regions, where limestone beds are at present being deposited. There are conditions under which the limestone may be deposited in an impure form, as, for instance, by the addition of clay, forming an argillaceous limestone, or of magnesia, which produces a magnesian limestone.

Certain minute animals (Infusoria) and plants (Diatoms) extract silica from the water for the construction of a siliceous test, and under certain conditions, chiefly in fresh-water deposits, these may be accumulated into a layer of *infusorial* or *diatomaceous earth*. Of *coals* little need be said here, since these strata will serve as a special topic. They have resulted from vegetable contributions to the earth's crust, under conditions favouring rapid burial and protection from destruction. Coals are of importance from an economic standpoint, rather than from their value as parts of the earth's strata; but, when carbonaceous shales and limestones are taken into account, it is found that vegetable contributions to the earth's crust are of much importance.

Conditions of Accumulation. — These several deposits, most of which are extremely important in the structure of the earth's crust, although being formed in all bodies of water, are being most rapidly deposited in the ocean, where also they are most widespread. Hence it is that the sedimentary strata of the world are most commonly of marine origin. That this is true we know from their fossils, which are usually the relics of marine animals. Furnished by the decay of the rocks, or the death of animals or plants, these deposits are gathered in the sea and accumulated, often to great depths, before finally being raised above its surface. The earth's crust is

changing in form: certain areas are slowly rising and others sinking. This we know partly by direct observation, partly by inference from the present position of sedimentary rocks on the very crest of mountains. If a coast line is suffering a gradual downsinking, the accumulating sediments may gather into a great thickness of strata, one deposited upon another. In places, thousands of feet of sediments have been thus accumulated. Those which are beneath become consolidated by pressure, and by a cement deposited from solution, by percolating water, and when finally the series of strata is elevated above sea-level, what was once an unconsolidated stratum of sand has been transformed into a hard sandstone. This, in general, is the way in which our sedimentary series has been formed and placed in the present position as a part of the land.

In the ocean the fragments, being deposited by gravity, tend to build up layers of nearly horizontal strata, thicker and coarser near the shore, and thinning out as well as becoming of finer texture in a seaward direction. They vary from horizontality only when the irregularities of currents or waves cause a local variation of position, or when the form of the ocean bottom is uneven. Such cases are, comparatively speaking, both rare and local, and it is a safe statement to make, in general, that sedimentary layers are originally horizontal. Yet, when these strata are found upon the land, they are scarcely ever perfectly horizontal, and are frequently tilted at a high angle. The same cause which brought about the depression and elevation of the ocean bottom, and which is still taking place, — namely, the contraction of the earth, — has caused the crust to wrinkle, the layers to bend and break, and mountains to form. Hence

it is that we find the strata so often thrown out of the horizontal and cast into folds, or broken and faulted.

Igneous Rocks.¹—Rocks which have been formed by the cooling of molten material coming from within the earth are known as igneous. In some parts of the earth they are extremely abundant, while in others they are practically absent. Thus in the United States the Cordilleras abound in igneous intrusions and extrusions, while in the Central States they are very rare. In general, it may be said that igneous rocks abound in highly tilted strata, and are liable to be rare in those which are nearly horizontal. The same thing may be stated in another way; namely, that igneous rocks are most abundant in mountainous regions, or in regions where mountains formerly existed but have been destroyed by erosion. Of the former the Cordilleras furnish an illustration; of the latter, New England.

Igneous rocks vary greatly in character in two ways: chemical composition and physical structure. On the one hand there are some having from sixty to seventy per cent of silica, on the other, forty per cent or even less, while between these two extremes there is every gradation in chemical composition. Accompanying this variation there is naturally a wide difference in mineralogical composition. There are, for instance, granites which have orthoclase feldspar, quartz, and some other minerals; syenites containing the same minerals with the exception of quartz; diorite carrying hornblende and plagioclase feldspar; and many other species, as will be seen in the accompanying table.

In structural features these vary from glassy to coarsely

¹ A scientific treatment of the igneous rocks will be found in Rosenbusch's *Mikroskopische Physiographie der Massigen Gesteine*.

crystalline. Certain rocks are natural glasses, others have a glassy groundmass with large, quite perfect crystals, porphyritic crystals, scattered through it, still others have a fine-grained granular structure called cryptocrystalline, and many are holocrystalline, or of a coarse-grained granitic structure. All of these various physical differences may be possessed by rocks having essentially the same chemical composition, and, indeed, all may be present in the same mass. This difference in structure is largely the result of a difference in the rate of cooling. A surface lava, cooling rapidly, may become a natural glass, because the minerals had not time to crystallize out of the molten magma, while the same lava, cooling slowly, might assume a granitic or holocrystalline structure.

Upon these two characters the following classification¹ is based. Those in the vertical columns are of essentially the same chemical composition, while in the horizontal rows the chemical variation is indicated by the change in mineralogical character.

The position of these igneous rocks in the earth's crust varies. They differ from the sedimentary strata principally in the lack of uniformity and regularity. So far as the chemical character is concerned, there is no uniformity of occurrence which can be predicted. Acid and basic lavas may be found intimately associated in the same region; or, on the other hand, only one kind of lava may occur. Also, the igneous masses may all be of uniform structure, or there may be holocrystalline, cryptocrystalline, porphyritic, and

¹ Adapted from Adams' table, which is based upon the Rosenbusch classification of igneous rocks. This table differs from the Adams table only in the omission of certain comparatively unimportant groups.

glassy, all in the same region. This variability is the result of causes which cannot be discussed in detail here. In general, it may be said that lavas are derived from a portion of the earth some distance beneath the surface, and are an expression of an effort of this molten material to escape. If they are successful in this effort, they flow out upon the surface, cool rapidly, and tend to become glassy or cryptocrystalline in structure; but if unsuccessful, they cool slowly, and become well crystallized. Their variation in chemical composition is apparently the result of a variation in source of supply, although it is difficult to explain why neighbouring volcanoes send forth different lavas, and still more difficult to understand why the same volcano may at different times erupt different lavas.

In the effort to attain the surface, some igneous rocks escape from the earth, and issue as lavas from a volcanic vent, or from a fissure. These *extruded* or *effusive* rocks may flow out quietly as lava, or, by the explosive violence of the contained water, they may be blown into fragments of volcanic ash or pumice. In both these cases there is a tendency to build up a cone about the vent, although, where the vent is a great crack or fissure, large areas of country may be flooded and no cone constructed. An ordinary volcano erupts lava which solidifies within a radius of a few miles from the vent, and its influence is therefore local; but volcanic ash, rising high in the air, may float great distances either in the air or on the water. Later these deposits may be destroyed by denudation, and their fragments distributed in the ocean as sedimentary deposits; or, on the other hand, they may themselves be buried without change, and become a part of a bedded series of sedimentary strata.

While vast quantities of lava escape to the surface, vast quantities, also, are unsuccessful in their effort to escape. Such rocks are often found solidified in the other rocks into which they have been intruded. The volcanic vent, when the activity ceases, becomes clogged with the contained lava, and there is a plug or *volcanic neck* of solidified lava extending deep down into the earth. At times, the lavas find it easier to raise the strata in an arch than to break through them, and a *laccolite*, or well of lava, is formed. *Intruded sheets* of lava are found between the sedimentary strata, and at times these are rent asunder and masses of molten rock forced into them, forming great areas or *bosses*, such as the granite masses. These various rocks are said to be *intruded* or *intrusive*, and those like granite, which are intruded at great depths, are called *plutonic* or deep-seated. They are revealed only after the thick overlying layers have been removed.

From all of these igneous masses, *dikes*, or narrow sheets of lava, may extend, sometimes as feeders, sometimes as offshoots, and where the volcanic history has been complex, there may be a great complexity in character and position of the igneous rocks. They may cut each other, or traverse any of the groups of sedimentary or metamorphic strata. Sometimes their boundaries are sharply defined and regular, but more commonly they are irregular, and even at times indefinite. It is more common for them to traverse the surrounding rocks in a more or less vertical sheet, but cases are numerous where such intrusions are nearly horizontal.

For a study of that part of economic geology which deals with ore deposits, some knowledge of igneous rocks is necessary, for the reason that many such deposits are in greater

or less degree due to their presence. By direct contact, these heated intrusions have, in some cases, caused an accumulation of valuable ore. Still more commonly have they furnished the ore which has been gathered together in the vein; for nearly all, if not all, igneous rocks carry a certain percentage of the metals which, by the decay of the minerals, may become a part of the sedimentary series, or which may be taken directly by percolating water and gathered into a vein.

Metamorphic Rocks.—The third great group is classed as metamorphic. Originally these were supposed to mark an early stage in the history of the earth, possibly the original crust of the earth, and for some this may still be true, since they lie beneath the oldest known sedimentary strata, and when these were formed had their present character. They are the oldest *known* rocks, but to assume that they actually are the *oldest* is going farther than the facts warrant. Of late years, studies of these metamorphic districts have tended to withdraw from the old Azoic or Archean group many areas which were formerly supposed to be of this age. It is found that both sedimentary and igneous rocks may be made to lose their characters and become metamorphosed. This may happen by contact with large masses of plutonic igneous rocks, as well as in the centre of mountain chains, where the strata have been folded and crushed. The first is called contact; the second, regional metamorphism. As a result of this change, it happens that strata of much younger age than the true Archean may have very nearly the structure of the Archean series. Parts of the New England hills, long classed as Archean, are now known to be of much later age. Whether the real Archean rocks owe their structure

to the same cause, or whether the resemblance is one of coincidence, we are hardly in the position at present to state, although the tendency of the recent studies is toward the belief that they are the same in cause as well as in character.

There is a wonderful variety of structure in the metamorphic series. It might be said that every consolidated sedimentary layer is more or less metamorphosed. There is every gradation from the incoherent accumulation of coral debris to limestone and *marble*, from sandstone to its metamorphic representative *quartzite*, and from clay shale to its representative among the metamorphics, *slate* and *phyllite*. These, in turn, grade into crystalline rocks so greatly metamorphosed that the original condition cannot be determined. Leaving out of consideration these three groups which can be easily traced to their source, the crystalline metamorphics may be divided in general into two groups—*gneisses* and *schists*. A crystalline structure, often nearly as marked as in igneous rocks, is a common feature of these two groups, and they are alike also in the possession of schistose structure. In the schists proper, it is present in such a marked degree that the rock cleaves with facility in a given direction, while in the massive gneisses it is present only as a banding of some of the minerals, so that they frequently resemble very closely a granite. Other distinctions than that of schistosity are difficult to maintain, although it is common to find in schists a greater predominance of mica.

A great number of sub-varieties of these metamorphics are known. We have, for instance, quartz schists, amphibole schists, mica schists, chlorite schists, hornblende gneisses, augite gneisses, and a large number of others; but in all the foliated structure is the uniform and general feature. The

minerals are arranged in bands, in strings, or, in some cases, simply with their major axes oriented in parallelism, and this gives the gneissic structure. Shales and slates are found passing over to chlorite schists, conglomerates and granites to gneisses or mica schists, and in all cases the direction of the schistose structure is at right angles to the direction of the pressure which is causing the metamorphism.

Upon a study of the rock it is found that there are several ways in which this gneissic or schistose structure may originate. It may be the result of the crushing of the component minerals and their arrangement in parallel bands; or it may be due to the stretching of some of the minerals which are so nearly plastic that they do not crush; or, finally and most commonly, it may be due to the development of new minerals, the result of heat, pressure, and attendant conditions. These facts may be verified by observation and study, and in many cases it is possible also to observe the cause for the metamorphism, as, for instance, when the strata occur in the core of a mountain chain. Both the igneous and sedimentary series furnish the material upon which metamorphism acts, and it is found that the same kind of metamorphic may be produced from sources as opposite in character as igneous and sedimentary rocks. This result, which at first thought seems an anomaly, is easily understood when we consider that a conglomerate may have the same chemical composition as a granite, or a shale as a diorite. Metamorphism takes account of material available rather than the particular form of this material,—of the chemical rather than the structural features.

While it is possible that the old Archean series *may* represent the original crust of the earth, either in its original

condition or else altered by metamorphism, yet, since the same kinds of metamorphics are known to be produced by simple and easily studied and comprehended changes in known rocks, it is natural that one should be skeptical of an explanation which has for its support merely hypothesis. It seems probable that the great mass of Archean strata will be found to be metamorphosed sediments and eruptives, just as many similar but more recent gneisses and schists are known to be, although so far all efforts to prove this have been futile.

Geological Age of Rocks.—In a study of the rocks and their relations one to another, it is necessary to have something more upon which to base our studies than their mere chemical and physical characters. It is desirable to be able to refer to them according to age, and to differentiate between a shale formed in the first ages of the earth's history and one formed in more recent periods. It was at one time thought that such a classification in general was possible upon a mineralogical basis; but more extended studies have shown that there is no uniformity of this sort, but that in any age strata of the same mineralogical composition are liable to be formed.

Age of Metamorphic Rocks.—Naturally the basis for a classification of rocks according to age must be a study of their relations one to another in the field. If one sedimentary layer is found resting on another, it seems probable that the lower layer is the older. In the case of eruptives and metamorphics this is not necessarily so. The bedding of a metamorphic rock may be mere schistosity of secondary origin, and hence of no value in determining the relative age of the layers. In the true Archean rocks a certain time-

classification has been made out in places; but it is of local value only, and so far no valid grounds for extending it have been found. This much is known, however, that a certain portion of the metamorphic series, the greater part apparently, belongs to the lowest and oldest geological period. So far as we know no fossils exist there, no sedimentary layers are found among them, and all known sedimentary and fossil-bearing strata are of later origin.

Age of Eruptive Rocks. — With eruptive rocks, we are in no way better able to construct a chronology. Locally, it is possible in most cases to determine the relative age of associated eruptives, or of the erupted rock, and the one through which it passes; but this cannot be extended beyond the locality where it is observed, because in any part of the earth's crust, or in any period, any kind of an igneous magma may have been erupted. Still, if the igneous mass cuts a certain other rock, it is the later of the two, and so far we have a chronology; but only a hundred years ago, a dike may have cut an Archean series, and to-day we would be unable to tell whether it were a hundred years old, or many ages. Sometimes, by a careful study of a region, it is possible to determine quite accurately the age of an igneous mass. Thus in the eastern United States great dikes of an igneous rock, diabase, are found cutting the strata of all ages from the earliest down to the time of the Triassic period, but nowhere crossing the later layers. The age of these lavas is, therefore, Triassic. At times, an igneous rock is in such a position in the stratified series that one is unable to tell whether it was formed at the same time as these, or later; that is, whether it flowed out as an extrusive lava sheet, while the sediments were being formed, or whether it

were later intruded between the layers. If intruded, it may follow the bedding planes very closely, though it may cut from one layer to another, which would not be the case if extruded. An intruded sheet would show the effect of heat at both the upper and lower contact, and would be liable to intrude dikes into the overlying layer. An extruded lava would not produce these effects, but the sedimentary layer above would probably contain fragments of the lava. These are about the only means of determining the age of an eruptive, although it may be added that if a rock is coarsely crystalline and granitic, it is usually old, for such masses are intruded into the earth at considerable depths, and are not revealed until the overlying layers are removed, which is usually a slow process. In very high mountain regions, where erosion is rapid, and in the case of thick lava flows, there are exceptions to this rule, so that it is only of very general application.

Age of Sedimentary Rocks. — There is a much more satisfactory chronology for the sedimentary strata, the rocks which, so far as revealed, predominate in the earth's crust, although in years we can make no estimate at all approximate to the truth. By the folding of the mountains in Pennsylvania, and by the erosion of the streams which have breached them, there are found to be revealed not far from 40,000 feet of sedimentary strata, one layer upon another. These were all deposited in water, and apparently under the same laws which govern the accumulation of sedimentary deposits to-day. This must have represented a vast lapse of time, yet there are represented here less than one-half of the total thickness of the geological column from the Archean to the present. Evidently this period of time must be estimated in

millions of years, but how many it is impossible to say, and those who have hazarded guesses have made estimates ranging from ten to several hundred millions of years. There are no facts upon which to base such an estimate, because the conditions are too variable, and our knowledge of them entirely too obscure.

Knowing, however, that one layer is above another, and is hence later, we have a valuable local indication of relative age and, as far as a given stratum, or a group of strata, can be traced, the chronology is correct. But it is possible to extend this chronology even beyond the limits possible by directly tracing a given series of layers, for it is found that in these sedimentary strata there are fossils, relics of animal and plant life of the time when the rocks were formed. The fauna and flora of the world to-day are marked by a general uniformity of character, certain groups of animals and plants predominating, which give character to the life of the period as compared with those which preceded. Assuming that this has been the case in the past (and this is more than a mere assumption, for it is verified by a study of the fossils), an examination of the fossil contents gives us a chronology which, in its broadest features, is of world-wide application. Before a certain series of rocks was deposited, there were no vertebrated animals, then fishes appeared, then reptiles, and mammals, and birds. If, now, in a certain stratum the petrified bone of a bird is found, it can be affirmed definitely that this stratum belongs to a period later than the time of appearance of the first birds. A knowledge of the exact species of the bird might even indicate the exact period. Certainly, this, taken together with a knowledge of other fossils from the same bed, would furnish a means of identification of this bed as a part of a general group.

The knowledge upon which our ability to make these determinations is based has been slowly acquired by a long and careful study of many different fields, and, as far as the general groups are concerned, it is a safe statement to make that ordinarily a knowledge of the fossil contents will serve to place a certain stratum in its proper position in the geological time-scale. This study has proved that there has been a development, an evolution of forms, from simple to more complex, and that, in each succeeding age, the prevailing types of life are progressively higher. In some places, the divisional line between two ages is indefinite and difficult to draw, but generally it is sufficiently well defined for the purposes of division. New types seem, at times, to have developed rapidly, and to have displaced the older types, in a period of time so brief that the gradation is not marked. Yet, in various parts of the earth, every gradation, generally speaking, is found. The division into ages is usually based, however, upon fields where no gradation exists, but where the dividing line is sharp, and these places are generally regions where for a time sedimentation was interrupted. That is to say, a region of marine deposit was transformed to dry land for a period of sufficient duration to admit of the development of new types, and then a submergence brought these animals into the condition of fossils in beds above the earlier ones¹ (Fig. 1). Having been demonstrated for such a place, the observation can be extended to other areas.

For the minor details of the geological time-scale, the classification is less satisfactory. Just as at present the fauna of Australia is widely different from that of America, so in the past, contemporaneous deposits, even when not far

¹ This is known as an unconformity.

removed geographically, may have entombed widely different species. While the presence of certain types of mammals, chiefly man, would serve to indicate the general contemporaneity of the deposits of Australia and America, it is quite unlikely that, from a study of the fossils alone, the two deposits, of exactly the same age, would be placed in the same minor subdivision in the scale. Recognizing this, geologists rarely attempt to correlate the subdivisions of an age in different regions, but confine their use to local areas.

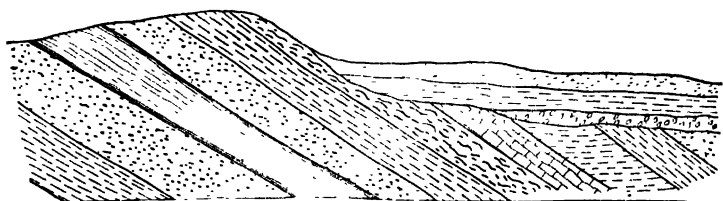


FIG. 1. — UNCONFORMITY. The inclined strata were deposited and tilted before the horizontal strata were laid down. Between the time of deposit of the tilted strata and that of the horizontal, several geological ages may have elapsed.

Thus the term Silurian is used in all countries, but the subdivision Niagara is a local New York term, and indicates a part of the Silurian, whose position in the New York column is perfectly definite, and whose fauna is practically uniform. How far such a term can be extended, even on the same continent, depends upon a variety of circumstances, but, generally speaking, its use is local.

The stratified rocks are divided, according to these features, into a chronological series of large divisions of a general nature, and subdivisions of local nature. In the table which follows, the American terms are given, and no attempt is made to correlate these with their probable equivalents in other countries.

CENOZOIC	QUATERNARY ¹ (Age of Man)		RECENT	
	TERTIARY ² (Age of Mammals)		PLEISTOCENE	
MESOZOIC (Age of Reptiles)	CRETACEOUS		PLIOCENE	
	JURA-TRIAS		MIOCENE	
PALÆOZOIC	CARBONIFEROUS (Age of Plants)		Eocene ³	
	DEVONIAN (Age of Fishes)		LARAMIE	
			UPPER CRETACEOUS	
			LOWER CRETACEOUS	
	SILURIAN (Age of Invertebrates)		JURASSIC	
			TRIASSIC ⁴	
			PERMIAN	
			COAL MEASURES	
	SILURIAN (Age of Invertebrates)		LOWER CARBONIFEROUS or SUB-CARBONIFEROUS	
			CATSKILL	
			CHEMUNG	Chemung ⁶
			HAMILTON	Portage
	SILURIAN (Age of Invertebrates)		CORNIFEROUS	Genesee
				Hamilton
				Marcellus
				Corniferous
	SILURIAN (Age of Invertebrates)			Schoharie
				Canda-Gallo
	SILURIAN (Age of Invertebrates)		ONISKANY	
			LOWER Helderberg	
			SALINA	
			NIAGARA	Niagara
	SILURIAN (Age of Invertebrates)			Clinton
				Medina
				Cincinnati
				Utica
	SILURIAN (Age of Invertebrates)		TRENTON	Trenton
				Chazy
			CANADIAN	Quebec
				Calceolous
	SILURIAN (Age of Invertebrates)		UPPER CAMBRIAN	
			MIDDLE CAMBRIAN	
			LOWER CAMBRIAN	
	SILURIAN (Age of Invertebrates)		KIOWANAWAN ⁶	
			UPPER HURONIAN	
			LOWER HURONIAN	
	SILURIAN (Age of Invertebrates)		LAURENTIAN	
			(Fundamental Complex)	

¹ There is a tendency in some directions to substitute the term Pleistocene for Quaternary.

² The United States Geological Survey adopts the term Neocene to include the Pliocene and Miocene.

³ In Europe, the subdivisions of the Tertiary are particularly well marked, and a fourth division, Oligocene, is recognized as occurring between the Eocene and Miocene.

⁴ The term Newark is now used by the United States Geological Survey to include the strata of the eastern states, which were formerly called Triassic. The Jurassic and Triassic periods are not well developed in America.

(For continuation of notes, see following page.)

The above table gives the best recognized names for the most prominent members of the geological column. Minor subdivisions are introduced only in the case of the New York Devonian and Silurian. Each period contains many minor subdivisions based upon local studies, and, in the Cretaceous, for instance, the names for the minor subdivisions of the Atlantic coast series differ from those of the central western states, and these in turn are different from the names applied to the Cretaceous strata of the Pacific coast. The subdivisions are therefore of local value only, and will be learned by a study of localities.

Disturbance of the Rocks.—While in places the surface of the earth is composed of sedimentary rocks in orderly succession, one above another, and in a very nearly horizontal position, there are large areas where they lie in very much disturbed positions. The earth is apparently losing heat and, in consequence, contracting, the outer crust endeavouring to accommodate itself to the constantly decreasing size of the interior. It is, consequently, wrinkling very much as an apple wrinkles by the loss of water as it dries. Speaking broadly, and without entering into the discussion of the various theories, this seems best to account for the continental and mountain folds of the earth's crust.

⁵ Some of the minor divisions or epochs of the Devonian and Silurian are introduced here, because they are well developed and well worked out in New York state.

⁶ In England, the term Ordovician is used as the equivalent of Lower Silurian, and the name Silurian is confined to the upper division, but this has not been generally adopted in this country.

⁷ This division of the Cambrian is more perfectly developed in Europe than in the United States.

⁸ This division of the pre-Cambrian rocks is based on the Lake Superior region, where these strata are better exposed and more fully studied than in any other part of the country. The Archean includes those rocks which show no sign of elastic origin, and have no indications of organic remains. Algonkian includes the strata between the true Archean and the true Cambrian. They show signs of sedimentary origin, and, when more carefully explored, may yield fossils. The rocks are distinctly older than the Cambrian, and also markedly younger than the Archean, which may be in part the original crust of the earth.

As a result of this process, portions of the land are rising, others sinking, with reference to the datum-plane of sea-level. It is because of these changes that the great thickness of sedimentary rocks is possible. Of the 40,000 feet of such strata in the Pennsylvania column, the greater number are rocks formed not far from the shore lines. Such a vast accumulation under such conditions proves a long-continued sinking of the sea-bottom at this point. The fact of the existence of these marine rocks at present above sea-level points conclusively to a subsequent upheaval. A study of the region has proved that, from the Cambrian to the close of the Carboniferous period, the sea-bottom sank; then followed an elevation, and since that period this elevation has been maintained and even added to, although the *actual* elevation has been reduced by the long-continued erosion to which the area has been subjected.

Such changes in relative position of land and sea are among the most common phenomena with which the geologist has to deal. Not only have they taken place in the past, but, even at the present time, they are being registered along the coast lines, as slow movements of the land, just as in the past. The presence of peat bogs and submerged forests beneath sea-level, and of beaches and wave-cut cliffs above the present shore line, is recorded on many coasts; and if more evidence is needed, it is necessary to state merely that, on the coast of Sweden, man himself has recorded the presence and amount of these changes by actual observations upon fixed bench-marks.

At times the land is bodily uplifted, forming plains or plateaus, according to the amount of uplift. In such cases, although elevated above sea-level, the rocks retain their

original horizontality. If the uplift is unequal, the rocks may break along a given plane, and upon one side move higher than on the other, forming a *fault*, — a dislocation of the rocks accompanied by differential movement. The fault plane may be vertical, or it may dip, or *hade*, one way or the other. The side which is the higher is called the *upthrow* side, that which is lower the *downthrow*, without regard to which side has actually moved. A fault in which the hade is toward the downthrow is called a *normal fault* (Fig. 2); where toward the upthrow, a *reverse fault* (Fig. 2), and here a vertical shaft will pierce the same stratum twice,

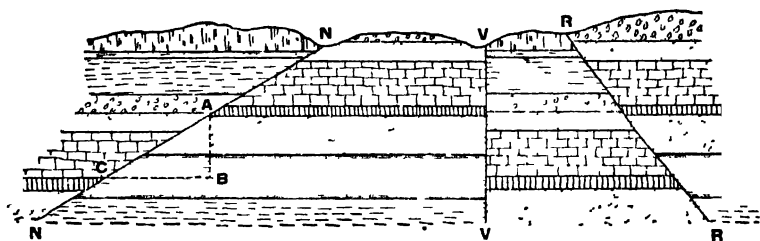


FIG. 2 — Cross-section showing normal fault (N), vertical fault (V), and reverse fault (R). AB, downthrow, BC, lateral throw.

once on each side of the fault plane. Where the fault plane is nearly horizontal, or nearly parallel to the bedding, it is called an *overthrust fault*, because by this means earlier strata may be thrust over upon later strata. When the horizontal direction of a fault plane is in the direction of the dip of the strata, the fault is a *dip fault*; when at right angles to this, a *strike fault* (Fig. 3).

Folding of strata is even more common than faulting, for even the most rigid of rocks may bend when the pressure of the overlying rocks is sufficient to prevent them from breaking. A simple upfold of the rocks is an *anticline*

(Fig. 3); a downward fold is a *syncline* (Fig. 3); and a single rise, followed by a horizontal or nearly horizontal condition of the strata, is a *monocline*. The direction in which the rocks pitch into the earth is the *dip*, and the angle of dip is the angle made by this plane with the horizontal. The *strike* is a horizontal line at right angles to the dip and in the plane of the dip, or the strike is the horizontal direction of the outcropping stratum. Folding of rocks in mountains may be of one or all of these simple types, or it may be complicated by faulting, or the folding itself may be extremely complex. At times the rocks are



FIG. 3. — Section showing anticlinal (A) and synclinal folds (B), overturned folds (C), and a strike fault (D). 1-2, direction of dip.

folded so far that they become overturned, in which case older strata appear to lie upon younger, and a careful study is necessary to detect the cause. The folds themselves may be folded, and all of these complications added to the intrusion of igneous rocks, the metamorphism of sedimentary strata, and the subsequent erosion of the area, gives to us an extremely complex maze of rocks. It is in such places that mines are commonly located.¹

¹ This brief statement of such geological facts and principles as seem absolutely necessary for a comprehension of the elements of economic geology might be advantageously supplemented by a thorough course in geology. The reader is referred to Geikie's *Text-Book of Geology*, Geikie's *Class-Book of Geology*, Jukes-Browne's *Physical Geology*, Dana's *Manual of Geology*, or Le Conte's *Elements of Geology*, for a complete presentation of the subject.

CHAPTER III.

PHYSICAL GEOGRAPHY AND GEOLOGY OF THE UNITED STATES.

THERE are five geographical zones in the United States: (1) the southern coastal plains; (2) the mountains of the eastern states; (3) the inland plains and plateaus of the central western and southern states; (4) the Lake Superior hilly region, a southern extension of the Canadian Highlands; (5) the Cordilleran region, including the Rockies, Sierra Nevadas, and Coast ranges, with their enclosed plateaus and basins. These are capable of much more minute subdivision, but this will serve as a general classification upon which to base the summary which follows.

Coastal Plains.— There are several distinct parts to this area, all of which, however, are marked by the possession of the general features of a plain extending inward from the coast line, and composed of recent strata. The *Quaternary Coastal Plains*, or coastal plains proper, a subdivision of this general region, are the most recent additions to this country; being, in fact, old sea-bottoms, so recently elevated above sea-level that in many places the fossils entombed in their strata are the same as the living species in the neighbouring ocean. The rocks here are horizontal, or nearly so, and consist of the usual materials formed along shore lines. Sandstones clays, and conglomerates predominate, and while in some places the strata are partly or completely consolidated, for the most part they are still incoherent deposits.

Their origin has been partly from the action of waves upon the old shore line, partly from river deposits assorted and distributed by the oceanic waves and currents. Just such a deposit is being formed near the shore in these same regions at present.

The coastal plains, which exist in New Jersey as a narrow strip and are not found north of this state, increase in size toward the south, until in Texas they have a width, in places, of from forty to fifty miles. It is proper to include here, also, the delta and lower flood plains of the Mississippi, which are in part the elevated deposits of this river, formed in a great estuary, in part the flood plain deposits of the river formed since the elevation of the region. In topography, these plains are extremely simple. Where they attain their best development, in Texas, they are exceedingly young, so young, in fact, that a perfect system of drainage has not yet been established upon them. There is a monotonous stretch of dead level plain, relieved only here and there, where some stream, extending out from the interior, has sunk its channel to a slight depth in the strata, and furnished a drainage sufficient for the growth of trees. Between the streams there are flat-topped divides, swampy, and occupied by a growth of unnutritious swamp grass, because undrained. A few small streams have begun to develop in the areas between the extended streams, but as yet very little progress has been made. Skirting this plain on the seaward side is a strip of varying width, in which new land is being made. Bars are being thrown across the river mouths by the combined action of tides, waves, and winds; lagoons are being formed, and these are being filled with sediment and by the growth of marsh vegetation.

This region is at present of very little economic importance, for the reason that it is inaccessible. What stores of clay there may be below the surface, or what local deposits of iron, or even of lignite, where streams have brought down vegetable matter, can only be conjectured by a comparison with the similar deposits formed in the age immediately preceding this, and at present existing in the region immediately to the landward. At present the only economic products in the region are the sands along the shore.

Florida Plains.—Florida, which forms a part of the general region under consideration, is a unique geographic unit. It is a region of Tertiary, essentially calcareous rocks built upon a submarine bank whose origin is not clear. Being situated in the warmer waters, coral growth was possible; and in this respect it differs from the other portions of the coastal plains, where the ocean water was freshened and clouded with sediment by the influx of river water. As Florida was, at the time of its construction, practically unaffected by land water, so also to-day we find no land streams extending across it. The drainage is that of newly developed streams, and the short time that they have been in possession of the land, together with other causes, has prevented them from draining the peninsula perfectly, and, consequently, immense swamps and shallow lakes exist as a feature of this geographic form. Since the streams of the Florida region are practically sediment-free, coral growth is still possible upon the shore and upon the off-lying banks, so that, by this means, added to the influence of the mangrove tree, which grows with its roots in the salt water, the coast of Florida is growing outward.

Tertiary Coastal Plains.—While the coral beds of the

Florida peninsula were being developed, the coast line of the southeastern states was some distance farther inland than at present. This condition did not exist in New England, excepting in the off-lying islands; but from New York, southward to the Rio Grande, the land was lower, and, in general, the submergence increased to the southward. The submerged strip in Texas reached inland nearly as far as Austin, the present lower course of the Rio Grande was a great estuary, and an extensive embayment extended well up the valley of the Mississippi. Apparently the coastal conditions were not unlike those at present prevailing, and the deposits are just what we know to be forming along the present shore line. These strata have been uplifted without folding or extensive faulting, but are inclined gently seaward, giving a slight tilting with an increasing elevation inward.

Cretaceous Coastal Plains.—In the immediately preceding period, the Cretaceous, the geography of the country was vastly different from the present, the Rocky Mountains not having then been formed, and their area being in large part, occupied by oceanic water. The far west was separated from the east by an arm of the ocean, and in all these areas of water Cretaceous deposits were formed. There is no genetic difference between the plains formed in the west and those which are found skirting the eastern base of the Appalachians, but it will be necessary to divide these two areas and include the Texas Cretaceous with the other central and southern plains, and for the present consider only the Cretaceous deposits east of the Mississippi. The eastern coast line was still lower than in the Tertiary, which followed, and coastal plains were formed, remnants of which

are still found skirting the inner margin of the Tertiary Coastal Plains at Martha's Vineyard, Long Island, in parts of eastern New Jersey, in central Alabama, and north-eastern Mississippi, as well as elsewhere along this line. They are, for the most part, scarcely more disturbed, though slightly more consolidated than the Tertiary.

In these Tertiary and Cretaceous plains, the clays are usually still plastic, and the sands frequently only partially consolidated; but the coral rocks of the Florida region are more indurated, because calcareous rocks are easily consolidated by the action of percolating water. This series of rocks is prolific in certain classes of economic deposits. The clays of the Cretaceous and Tertiary in New Jersey and elsewhere, and the phosphate deposits of the South Carolina and Florida districts, are of primary importance; and in Texas there are extensive beds of lignite and of iron ore, while in Louisiana valuable salt deposits occur.

Triassic Coastal Area.—Between these two plains and the mountains, there are two intermediate areas, one composed of the older Palæozoic strata, forming the foot hills and the eastern plateaus of the Appalachians, the other an area of Triassic strata, which may be considered under the general division of the eastern plains, although, in reality, they belong to a type of their own. What the conditions were in Triassic times, it is not easy to say, nor can it be stated how extensive the Triassic deposits were. The strata existing at present are chiefly sandstones and conglomerates of shore line, or, as in the case of the Connecticut valley area, of estuarine origin. Local areas occur in the south; there is an extensive area in Pennsylvania and New Jersey, forming, in the latter state, the undulating plains between the High-

lands and the Cretaceous plains; and in the Connecticut valley there is an area extending from the Sound to the northern part of Massachusetts, narrowing toward the north, where, in the Triassic period, the head of a bay was situated.

During Triassic times, and also shortly afterwards, there prevailed in the region under consideration a period of volcanic activity, the last one to which the region east of the Mississippi has been subjected. Great flows of lava were poured out upon the surface in the Connecticut valley and New Jersey; and, both at this time and later, dikes of trap or diabase were intruded across the strata as well as between them. The period of volcanic activity was widespread, and the character of the erupted material moderately uniform from North Carolina to Nova Scotia. Not only were the Triassic strata themselves cut by these traps, but all the older rocks in the neighbourhood were also traversed, even to a considerable distance from the Triassic. With the beginning of the Cretaceous age, these eruptions ceased. The trap hills near Patterson, New Jersey, the Palisades of the Hudson, East and West Rock at New Haven, the Hanging Hills of Meriden in Connecticut, and Mt. Holyoke in Massachusetts, are all witnesses of this period of vulcanism.

Partly on account of the great age of the strata, partly as the result of the volcanic intrusions, and partly because the rocks have been subjected to folding and faulting, the sandstone of Triassic age is compact and well consolidated. When the texture is even, and the colour reddish brown, owing to the presence of iron, the sandstone of this age is of value for a building-stone; and its importance for this purpose is greatly increased by its nearness to the market.

There are also metalliferous deposits in the Triassic at the contact of the igneous rocks, but these are usually of but very little value.

Mountains of the Eastern States.—This area is divisible into two important geographic units, the Appalachians and the older Archean mountains of New England, which also extend southward, east of the Appalachians, and northward into Canada.

The Eastern Archean Mountains.—This area is a region of hills and low mountains, worn down to their very core, and consisting of rocks chiefly of metamorphic or of igneous origin, with here and there areas of Palæozoic strata. The region has had an exceedingly complicated history. It, together with a large portion of eastern Canada, consists chiefly of Archean rocks which, before the beginning of the Palæozoic era, were folded into a series of mountain folds of extremely complex structure and attitude, being even then composed of metamorphic and igneous rocks of the same character as the strata which at present constitute their mass. Since then they have been again folded so as to include Palæozoic rocks. This was a part of the land which furnished the sediment out of which the rocks of the Appalachians are constructed, and in this area must be included, not only much of eastern Canada and New England, but also the Adirondacks, the Highlands of New Jersey, and the low Archean hills east of the Appalachians in Pennsylvania, Maryland, and the more southern states.

The exact history of this area cannot be presented, but it is composed of distinctly igneous rocks (diorites, granites, syenites, etc.), and of metamorphic rocks, whose origin is uncertain, but which may be, in part, altered sedimentary

strata. At the beginning of the Cambrian period, not only were these rocks much folded, faulted, and metamorphosed, but also they were much denuded. The old Cambrian shore line can still be traced in places, as in the Adirondacks and on the western margin of the New Jersey Highlands. A new period of mountain growth occurred during the Palæozoic, presumably at the time of the growth of the Appalachians, for all the rocks included in these mountains are included here also. Apparently the folding was more intense in New England than in the Appalachians, since, by its action, the Palæozoic strata have in places been metamorphosed almost beyond recognition, while in the Appalachians they have not lost their character. It is probable also that the mountains were higher here, and that igneous rocks were again intruded into the mountain cores, and in places caused to flow out upon the surface. Be this as it may, we have, in the New England area and the northern and southern continuations of it, an extensive mountain region worn down to its very core, and revealing to us rocks which are apparently as old as any on the earth's surface.

Owing to its complex history and structure, there is, in this region, a great diversity of economic deposits. There occur here great areas of granite, of marble and slate, deposits of iron, and, in small quantities, practically all the metalliferous deposits. For reasons to be suggested later, the metalliferous minerals are not generally accumulated here in great abundance.

Appalachian Mountain Region.—The Appalachians proper are folded rocks of Palæozoic age. No later strata are included, because the mountains had practically ceased growing when these were deposited; and no earlier rocks are found

in the Appalachians proper, because erosion has not been carried to a sufficient depth to reveal the underlying platform, excepting to the east, where the Palæozoic strata were perhaps thinner and the mountains higher. Both to the north and the south the folds of the Appalachians die out, and on the western side they become lower, and finally merge into the plateau of the central states.

In these mountains, the topography is dependent upon the rock structure. The strata have been thrown into great waves or folds, sometimes sharp, sometimes broad, and usually pitching in the direction of their axes, which are nearly parallel to the trend of the mountains. The rocks are alternating sedimentary strata, with varying hardness and with a variable dip, usually at a considerable angle to the east or the west. Owing to the long continued erosion to which these mountains have been subjected since the close of the Carboniferous, the variations in hardness have had a marked influence in determining the topographic features. Where hard sandstone or conglomerate beds outcrop there are hills; and the valleys are usually located in the limestone belts, although some streams flow directly across the strike of the strata, and cut at right angles both the hard and the soft layers. The hills are linear, with their axes parallel to the mountain folds, and they often follow the irregularities of the outcropping strata, as these turn in passing from one fold to another.

This district furnishes us with much building-stone, slate, marble, iron, petroleum, nearly all the anthracite, and much of the bituminous coal of the country, as well as many other valuable materials in smaller quantities. The importance of mountainous districts, as producers of valuable ores, is due

chiefly to the fact that the rocks are folded, so that erosion reveals a great variety of strata, and that in mountains the conditions which favour the accumulation of such deposits are present; namely, the formation of cavities and the presence of eruptive rocks. The Appalachians are surprisingly free from eruptive rocks, while faults and cavities are much less frequent there than in the Rocky Mountains, so that the greater importance of the latter region as a producer of metals is easily understood. It is possible that the old New England mountains, at the time of their greatest development, simulated more closely the Rocky Mountains than do their smaller neighbours the Appalachians.

Central Plains.—Very nearly one-half of the country is included in this area. Commencing at the western margin of the Appalachians, where the rocks cease to be thrown into waves or folds, there is a series of plateaus and plains extending westward to the base of the Rocky Mountains and southward to the Gulf of Mexico. Already those portions of the plains which form the marginal and coastal areas of the east have been described. The portion which remains consists of Cretaceous and Palæozoic strata chiefly, though in Nebraska and vicinity the rocks were formed in a great inland sea of Tertiary age. Considering the area as a whole, the strata are very nearly horizontal, and the country a plain scored and eroded to a greater or less degree in different places, so that at times its character as a plain is almost destroyed.

The geology is by no means as simple as might be inferred from this statement. At different points, rocks of nearly all ages outcrop at the surface, and the present condition is the culmination of a complex history of elevation and sub-

mergence. The essential features of the entire region are the almost complete absence of igneous rocks, and the fact that the strata have been uplifted without marked disturbance. These statements must, however, be qualified, since in several places the strata are disturbed and igneous rocks are present. There is a broad gentle fold, in Ohio and the neighbouring states, known as the Cincinnati arch. In Missouri, a knob of igneous rock projects through the Palæozoic strata at Pilot Knob. A large area in Indian Territory and Arkansas has been extensively folded and subjected to igneous intrusion; and the same is true of a smaller region in Central Texas, northwest of Austin. The Black Hills also form an igneous and folded area in the midst of the plains, and there are other similar areas elsewhere. Some of these disturbed regions, as those of the Black Hills and Indian Territory, are actual disturbances in the plains; but others, as Pilot Knob, are islands of pre-Palæozoic age. These regions, though considerable in number, are small in extent when compared with the plains as a whole. Properly, they should be considered separately; but, in this generalized statement, they need only be mentioned as disturbances in the great area of almost universally horizontal rocks.

These strata, being practically undisturbed by folding, faulting, or volcanic intrusion, are not such as would be expected to yield up large stores of metallic wealth, yet much zinc and lead and some iron come from this area, while salt, gypsum, coal, petroleum, and gas, are found in great quantities in various parts of the region. The major part of the rocks are well-consolidated limestones, sandstones, and shales, so that in this area there is an almost inexhaustible supply of the non-crystalline building-stones.

Lake Superior Region.—In northern Michigan, Wisconsin, and Minnesota, there is a region of metamorphic rocks, a southern extension of the Canadian series, which, like those of New England, have had an extremely complicated history. Here there is a central core of complex Archean surrounded by later rocks, among which are late Archean, Algonkian, and Cambrian strata. This has been a mountainous region; but, unlike New England, it has not been subjected to intense Paleozoic folding, although since the first period of mountain-building there has been considerable folding and faulting, accompanied by the intrusion and extrusion of igneous rocks. It is now a hilly region, much less mountainous than New England, but, like this province, is an old mountain worn down to its roots. From here are obtained immense quantities of copper and iron, and in this area there are large stores of building-stones.

Cordilleran Region.¹—Toward the close of the Cretaceous there existed, in the area now occupied by the Cordilleras, a great sea with archipelagos, and perhaps even continuous masses of land, composed of older rocks. An extensive disturbance of the strata, which has not yet ceased, was then initiated. This disturbance extended from Alaska to southern South America, and, although in places the mountains are still growing, the disturbance has now passed its maximum, and is declining. In the course of its development the rocks were extensively faulted and folded, igneous rocks were intruded into the strata, and numerous volcanoes poured out floods of lava and quantities of volcanic ash

¹ Only for the purpose of a general statement can such a comprehensive term be allowed. This is in reality a very complex province, composed of several geographic units.

upon the surface, while during all this time erosion was at work attempting to wear away that which was elevated. The present Cordilleras have resulted from this complex interaction of forces.

All ages of strata, from the Archean to the Pleistocene, are included in this region, and very nearly every variety of rock is found there. By the folding, chains and ranges were built, and valleys formed between them, some of these being great basins and extensive plateaus. At first many of these valleys, including parts of the Great Basin, were partially enclosed seas, and finally lakes with an outflow to the sea; but, as the enclosing mountains grew higher and the climatic conditions changed, these became transformed into interior basin lakes, then salt lakes, and in many cases they eventually became completely desiccated. The deposits of these seas and lakes were in part incorporated in the later mountain folds, but the most recent of them still remain horizontal strata of gravels and clays, forming great flats between the mountains, often with no drainage to the sea.

In this region there exists very nearly every economic product of the earth's crust. There is probably no region of similar extent in the world where such a variety and abundance of mineral wealth is stored. Already in development it exceeds any other portion of the earth in the output of many metals, and its resources are only partly understood. The more valuable and better known substances only have been discovered, and of these there undoubtedly remain many yet to be found. There is, also, in this province a vast store of mineral wealth known to exist, but at present undeveloped on account of its inaccessibility and remoteness from the market. Among these may be mentioned building

and ornamental stones, clays, gypsum, salt, coal, and iron. The metals, such as gold, silver, lead, and copper, which are of sufficient value for transportation come chiefly from this region, and their output is increasing every year. Nature seems to have conspired to produce here the proper conditions for the accumulation of a great variety of valuable minerals in great abundance; and what would otherwise have been an uninviting and sparsely populated region has become, in consequence of this prodigality of nature, a well-populated region.

Summarized Geological History of the United States.

This in general states the geological features of the several provinces of the country. The history of its development may be inferred from this statement, but it seems well to supplement it by pointing out the main steps of this evolution; to put in a summarized form the sum of our knowledge of the geological evolution of the country as a whole and of the grander geographic features.

What the condition of the country was during the earliest geological ages is only obscurely understood; but since that time the history becomes progressively more clear. That there was land, however, is shown by the fact that sedimentary rocks were formed. It is evident that there were land areas in the eastern seaboard states, in Canada, the Lake Superior province, and in parts of the Cordilleras; but how extensive, or exactly where they were, cannot be stated. Besides these there were probably other Archean land areas, now destroyed, and buried beneath the later strata.

In Canada, and in some of the seaboard states, such as

New Jersey, the Archean seems to be divisible into two distinct groups of rocks, an older and a younger, the latter being derived from the former; and in places there is some ground for a still further subdivision. There is no part of the Archean in the country which is better understood than that of the Lake Superior province. Here there is a central core of Archean of great complexity, an old mountainous land area, from which were derived immense quantities of sedimentary material of pre-Cambrian age, which, although since then greatly folded and faulted, is still much less disturbed than any area of similar age in this country, so that its true and original composition can still be determined. It is, therefore, of great value as an indication of the conditions of that period. From a study of these rocks it is found that, as in many areas of more recent strata, both sedimentary and eruptive rocks occur, that a vast lapse of time was occupied in their formation, and that during this time mountain-folding and other orographic changes were in progress. Probably the history of this region was not distinctly unlike that of other Archean areas less easily studied.

At the close of the Archean, there were many land and probably mountainous regions in the country. There was a very large area extending from Labrador to Lake Superior, and thence northwestward toward the Arctic, besides certain areas in this country, as mentioned above. At present, the rocks of Archean age outcrop where they have been uncovered from beneath later strata, or perhaps, in places, as in some parts of Canada, where they have never been buried. Where they are now found we know that they existed; but how far they extended, and how many extensive areas of former land are now buried beneath the ocean, or beneath

later rocks, will probably never be known. The Archean rocks were highly metamorphosed in most places even in pre-Palæozoic times, though they have undoubtedly undergone some changes since then; and into these strata granitic and other igneous rocks were intruded in Archean as well as in later periods.

Around the margins of this land Cambrian sediments were accumulated. Such places show that shore lines existed not far from the seaboard of New England and also on the western side of the New Jersey highlands, indicating an island of considerable linear extent extending southwards from New England. A shore line skirted a part of the Adirondacks; and there were shore lines on the southern margin of the Lake Superior Archean region, in Texas, and in parts of the Cordilleras. The probable geographic conditions, indicated by these shore lines, were a series of islands, mountainous and generally linear, marking, in a very rough way, the merest outlines of the developing continent. The backbone of the Laurentian highlands in Canada was the most prominent land area; and linear islands or groups of islands extended along the eastern coast and in the Cordilleras, their greatest length being, in general, parallel to the present mountains of these two regions. Probably other islands existed, and perhaps the extent of the islands just described was really much greater than has been stated. It is an interesting fact that the present valley of the St. Lawrence was then a strait between New England and the Laurentian Archean land areas, the valley being thus early indicated. It is also worthy of note, that the present valley of the Mississippi was a sea ~~partly~~ ^{partly} enclosed on three sides, as at present, and that the eastern and western enclosing areas

sketched, roughly, the present though much later-formed mountains.

During the remainder of Palæozoic times, — that is, until the close of the Carboniferous, — the event of chief importance was the accumulation of vast quantities of sediment in the seas surrounding these land areas and furnished from their destruction by weathering and erosion. There must have been a slow and long-continued subsidence of the sea and a long-continued and vast destruction of the land areas. The sediment was furnished to the sea, where now the Appalachians exist, from a land area which probably extended seaward beyond the present eastern coast line. In the Cordilleras the events are less well determined.

Toward the close of the Palæozoic, much of the region of the Appalachians and of the central states became shallow water and marshy land, upon which the coal vegetation flourished; and the same is probably true of some parts of the Cordilleras. Immediately following this came the great revolution which culminated in the formation of the Appalachians and the elevation of the central states above sea-level, — an elevation which has been maintained since then, with occasional oscillations, but continuous elevation above the sea. The Jura-Trias ages were of little importance in the evolution of the eastern part of the continent, although some changes took place in the Appalachian district, the most important being an increased elevation accompanying the volcanic outbursts which caused the traps of the Palisades, the Connecticut valley, and elsewhere. In the west, however, this period was marked by the growth of the Sierra Nevadas and the addition of much land to that part of the continent.

At the beginning of the Cretaceous the outline of the

continent was tolerably well determined, and only finishing touches were necessary to complete its present form. The Pacific bathed the base of the Sierras, the Coast Range not then being formed; and along the eastern margin of the continent the ocean covered the eastern part of all the states from New Jersey to Georgia. Florida, the greater part of Alabama, Texas, and Arkansas were beneath the ocean, and an arm of the sea extended northward, along the line of the Rocky Mountains and the states east of them, beyond the confines of this country. Islands existed in this mediterranean sea, in Texas, Arkansas, Indian Territory, Dakota, and probably elsewhere, while in the Sierras arms of the ocean formed estuaries, or in some cases had been shut in to form lacustrine basins. The country east of the Mississippi was nearly completed, excepting for the addition of the coastal plains; but the western region was yet to be perfected.

During the Cretaceous period sediment accumulated in these inland seas and along the continent margin; and at its close the great inland sea was transformed to a dry land area with many lakes. The Coast Range was not then formed, nor were the Rocky Mountains more than begun. To the eastern coast a slight addition was made, but the Tertiary plains were yet unformed, and the Gulf of Mexico extended as an arm of the sea up the valley of the Mississippi for a considerable distance.

During the Tertiary period the Coast Range was developed, and vast floods of lava were poured out upon the surface. The Rocky Mountains were also formed then, and by these mountain-foldings great lakes were caused, partly in the Cordilleras, partly on the eastern margin. In

the Rockies also vast quantities of lava were erupted, and this period of volcanic activity is only just now, within recent geological times, brought to a close. The great Cordilleran lakes existed even into the Quaternary period, but most of them have been drained, while some were destroyed by mountain-folding and the lake sediments built into the mountains. Even now, however, some of the lacustrine basins exist as interior basins, although because of the aridity of the climate, they are not now occupied by water. The Great Salt Lake is a shrunken remnant of such a lake in a great basin.

By the close of the Tertiary period the southern and eastern coast was nearly completed, though in Quaternary times a slight addition has been made, particularly in the south. Two notable areas have been added to this coast, one the delta and flood plain of the Mississippi, the other the Florida Peninsula. Both of these areas, which form a part of the coastal plains, were formed partly by material deposited and partly by the elevation of the land.

At the close of the Tertiary period the land, in the north at least, was considerably higher than at present, and during the immediately succeeding period, the Pleistocene, the northern part of the continent, as far south as New York and Cincinnati, was covered by an ice sheet which has somewhat modified the topography and the drainage, partly by its erosive effect, but chiefly by means of the detritus which it has left scattered over the surface. This period, like all which preceded, has had its effect upon the economic resources of the country. It has given to us many of the brick clays, it has changed the character of the soil, often disastrously, and it has given us the lakes and waterfalls

which abound north of the southern margin of the glacial drift. Accompanying its presence there was a subsidence of the land in the north, which has transformed pre-existing river valleys into the estuaries and harbours which have been so influential in giving the northern states such importance in commerce.

This is, briefly, and without entering into details or proofs, the general evolution of the continent. Its form was roughly sketched in the very earliest period and it has been slowly perfected, although undoubtedly many changes yet await it. No adequate mention has been made of the effect of erosion during all this time, but this is of prime importance. Old lands have been worn down and the ruins deposited in the water to afterwards be again built into land and perhaps again transformed into sediment. Erosion and sculpturing have been ever-acting, and the present form of the continent is the resultant of the conflict between the two opposing forces; the one tending to build up, the other to tear down.

CHAPTER IV.

ORIGIN OF ORE DEPOSITS.

Original Condition. — Deposits of ore are accumulated under certain conditions which favour the gathering together of like kinds of minerals in concentrated form. It will be found, as the later pages are studied, that there are many diverse ways in which this accumulation is brought about, and that it is possible to offer a classification of ore deposits based upon origin.

What the original condition of metals and metalliferous deposits may have been cannot be said. There are some who believe that the interior of the earth is, in part at least, composed of unoxidized metals, and that the ores which we find in the rocks are, in reality, the form assumed by these elements when they reach the surface, and come under the influence of the surface conditions, where oxidizing combinations are prevalent. Be this as it may, igneous rocks, which bear to the surface the substances existing below the surface, contain in their mass a greater or less proportion of metals in mechanical or chemical combination. It requires no careful analysis, nor even a microscopic study, to detect iron and, frequently, manganese, in the form of their oxides, in these eruptive rocks. Sometimes, copper salts and other metalliferous compounds are present in sufficient quantities to be detected by the eye. Analyses have for a long time shown that rarer metals are present in small quantities in

many eruptive rocks; and very careful analyses of certain rocks, made for the purpose of determining the point, have shown that rare and precious metals are present. They seem to be more prevalent in the complex basic bisilicates, such as augite and hornblende, and hence the basic rocks (diorites, diabases, etc.) are more prolific producers of these metals than are the acid rocks.

It is to Sandberger¹ that we owe the first proof of these facts, although his experiments have been repeated and extended by others. Previous to the time of his observations, analyses of rocks had not revealed any but the more common metals; but by separating the olivine, hornblende, mica, etc., and analyzing these, he proved the existence of iron, nickel, copper, lead, zinc, tin, cobalt, and other metals. Since this study, nearly all metals have been found in the common minerals in appreciable quantities. Nearly all lithia micas contain tin; muscovite, although poor in other metals, usually contains copper; and black micas carry many metals. Sandberger also found the disseminated metals in slates, and he proved also that the veinstones might all be derived from the common rocks; for even fluorine is found in mica and barium in feldspar, while the other necessary elements are common enough.

Sedimentary strata, being all formed from material either directly or indirectly derived from igneous rocks, naturally contain these metals also, and the same holds true for metamorphic rocks. In other words, metals are disseminated through all rocks, being much more prevalent in some than in others, but generally being in such small quantities that only very careful analyses serve to prove their presence.

¹ Sandberger, *Untersuchungen über Erzgänge*.

Removal of Original Ores.—In order to bring these metals into concentrated form, some agent is necessary to act as a carrier, and this agent is usually the ever-present water. All rocks contain water. In the quarry, it is shown by the loss of weight when the quarried block is exposed to the dry air; in the volcano, its presence is proved by the clouds of steam which rise from the lava stream, and the vesicles and cavities which it causes in the lava by its expansion. This water was partly built into the rocks when they were formed; but partly, probably chiefly, it comes from the surface. During every rain, a part of the fall flows off as surface water; a considerable portion creeps through the soil and reappears in springs; but a small portion starts on an underground journey, during which it often penetrates to great depths, traverses hard and soft rocks alike, and is ever present as interstitial water in the microscopic crevices in the rocks.

Cold water, free from impurities, has little solvent power except for the most soluble minerals, such as salt, gypsum, or calcite; but very little of the underground water is pure. As it passes through the soil and the surface coating of vegetable matter, certain acids and gases are absorbed. These give to the water an increased solvent power, and as it descends it may eventually become so strongly acid, or so alkaline, that even the most insoluble substances are taken into solution. The temperature of the earth progressively increases as the depth is increased, and hence water at considerable depths attains a temperature often high above the boiling-point, so that its power as a solvent is vastly increased. Even ocean water carries in solution small quantities of gold, silver, and most other metals, and it is probable

that, under conditions of great heat, the percolating water of the earth becomes a solvent of as great power as many of our acids and alkalies. Its effect is expressed not alone by the material carried in solution and subsequently concentrated, but also, in many places, by alterations of the rock-forming minerals by the extraction of certain parts, or the addition of others. This form of change sometimes results in the complete destruction of one mineral and the formation of another.

Origin of Cavities. — Granting, as we must, that the imprisoned water of the earth bears ore^{*} in solution in many cases, there remains to be considered the more difficult subject of the manner in which this ore is concentrated. Many of the ores occur in cavities where they have been deposited from solution. Sometimes these cavities are only partly filled; at times they are completely filled; and it is not uncommonly the case that the cavities are not only filled but enlarged, the force which causes the mineral to be deposited being so great that the walls of the cavity are spread apart by the growing deposit.

Joint Planes (Plate II.). — The most numerous cavities are those formed by joint planes, cracks extending across the rocks in given directions and breaking them into blocks without any sensible motion or displacement. Joint planes are of two kinds, — incipient, or those whose presence is shown only when weathering develops them, and normal joint planes, which, even without the aid of weathering, are present as dividing planes in the rocks. They are of the same origin apparently, and differ merely in the amount of development. In igneous rocks there are joints of cooling, the result of contraction by the loss of heat. The basaltic columns and the concentric, nearly horizontal joint planes of

granite are illustrations of these. Sedimentary rocks are crossed by joints of contraction, due, perhaps, to the loss of water; for when these rocks are formed, a certain amount of water is built into their mass between the fragments, and this may be lost, causing a considerable contraction, when the strata are raised above sea-level and drained by erosion. There is, also, in these rocks a possible contraction due to the loss of heat; but whether this is often sufficient to account for joint planes is a question. The most common

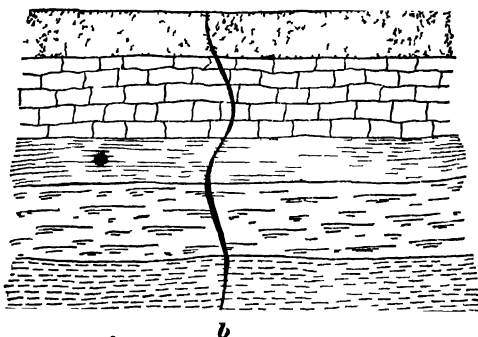


FIG. 4. —Horizontal strata crossed by an irregular fault line, *ab*, which upon faulting produces cavities as in Fig 4 *a*.

cause of these divisional planes in sedimentary and metamorphic rocks, and even in some igneous rocks, is contortion or folding, which causes stresses that are relieved by a fracturing or jointing; and hence all folded rocks are crossed by joints. These are generally nearly vertical; and two sets are commonly present, forming rhomboidal blocks, with angles frequently approaching the right angle and rarely very acute. Mineral veins are sometimes formed along these joints, which are channel-ways of easy passage for water; and even where veins are absent, small deposits are frequently found.

Fault Planes.—During the folding of rocks there are often formed faults or dislocations where one side slips past the other. These faults, being of deep-seated origin, often extend to great depths, and serve as passage-ways to the surface for the heated waters from below. If the fault plane were a perfectly straight line, the cavity would not be very great; but most commonly the fracture plane is irregular, and a series of cavities are thus often produced where two concave walls come to rest opposite

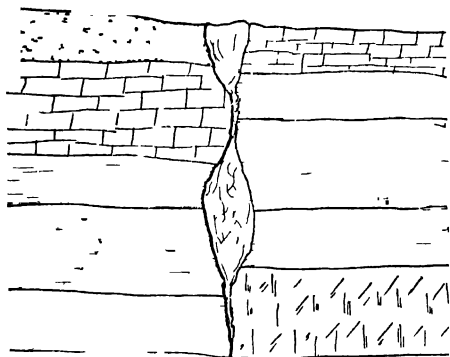


FIG 4a.—The same as FIG 4, showing the result of faulting along an irregular fault plane, producing alternate cavities and closed spaces

each other (Figs. 4 and 4a). By the motion of the rocks the uneven walls, rubbing against each other, tear off fragments, and produce in the vein a crushed substance, a *fault breccia*, which is common where two projecting parts of the vein are in contact. At times the faulting amounts to actual crushing, and the rocks are very badly brecciated. Such a series of cavities furnish an easy channel for the passage of water.

Solution Cavities.—Water, percolating through soluble rocks, such as limestone, dissolves the minerals, and forms cavities or caves which may later be filled with ore. Such

cavities are formed independently in some regions, but very frequently they have their beginning in joint planes; and in faulted regions the water, which later served to fill the vein with mineral, may at first have dissolved cavities in the enclosing rocks.

Minor Cavities. — Cavities exist in lava where there was a lack of supply of material, or, more frequently, where superheated water expands into steam, and produces a pumiceous or scoriaceous lava. So, also, in sedimentary rocks there may be original cavities (usually on a small scale) where there was a lack of material, or where some soluble portion may have been dissolved after the formation of the rock, as, for instance, in or around fossils. The contact of sedimentary and igneous rocks, or of two diverse series of strata, owing partly to the difference in character of the two, and partly to the presence of minute cavities, is a plane of weakness, along which the underground water finds a passage. Also the more porous rocks, such as sandstone, form channels, as is proved by the fact that artesian wells are found in such strata when bounded above and below by more impermeable layers. Besides these, there are numerous other cavities of small size and minor importance.

Classification of Ore Deposits. — There have been many classifications of ore deposits offered, and attempts have been made to classify them upon each of the three following bases: (1) mineral contents, (2) form of deposit, (3) origin of deposit. The first, that based upon mineral contents, is far from satisfactory, since the ores of silver, copper, zinc, and many others are all found in the same form of deposit derived in the same manner. It is not scientific; and yet in any economic study this must serve as a primary basis for

classification. An attempt to study ore deposits upon any other basis would involve much confusion, since it would be necessary to consider the veins of one class, as iron, for instance, then for the other metals in succession; and the study of any one metal would be scattered throughout various chapters. Therefore, as the primary basis for our study, we must adopt the metal. The more scientific classification would discard the above and consider the relation of the ore deposit to its surroundings; for if we have a vein of a particular form and origin, why should it be important whether it is one of lead or of copper, since both may be formed in the same way, and may even be present in the same vein?

The great majority of classifications, apart from the economic, have been based upon the form assumed by the deposit rather than upon the origin. This, it seems, advances a matter of secondary importance to the first rank, and in the classification which is given here origin has been considered as of prime importance, and form of secondary importance.¹ Carrying this scheme out to the end, and losing sight of

¹ Other classifications are discussed in various books upon economic geology and upon ore deposits, and will not be considered here. Some of the subdivisions in this scheme are taken from Whitney's classification, which is most currently accepted in this country, and is by far the best of any based upon the form of the deposit. The classification here given had been used for two years by the author in the class in economic geology at Cornell University before his attention was called to the fact that a similar classification was in use at the Houghton Mining School in Michigan. Its author, Dr. M. E. Wadsworth, published this classification in the early part of 1893 (Report of Michigan State Board of Geological Survey for 1891-92, p. 144. It was previously published in the Catalogue of the Michigan Mining School at Houghton), and so far as it coincides with this classification Dr. Wadsworth has priority, both of use and publication, although in the two cases the scheme was originated independently.

the economic bearing, the character of the ore itself would be considered as of third importance.

The following is the classification based primarily upon origin and secondarily upon form:¹—

- | | | |
|----------------|---------------------|------------------------|
| I. Eruptive | { (a) Disseminated. | |
| | { (b) Massive. | |
| II. Mechanical | (Sedimentary). | |
| | (a) Precipitated. | |
| | | { i. Chamber deposits. |
| | (b) True veins | ii. Gash veins. |
| | | iii. Fissure veins. |
| | | iv. Ore channels. |
| III. Chemical | (c) Replacement. | |
| | (d) Impregnation. | |
| | (e) Concretionary. | |
| | (f) Segregated. | |
| | (g) Contact | { i. By sublimation. |
| | | ii. By concentration. |

I. Eruptive Deposits.—Already the eruptive deposits of original disseminated nature have been described, and it has been stated that nearly all eruptive rocks contain ores in

¹ This classification might be much more minutely subdivided, but this seems hardly necessary for our purpose. Various classifications of ore deposits will be found in the following works: Report of Michigan State Board of Geological Survey for 1891-92, p. 144; Davies, *Metalliferous Minerals and Mining*, p. 8; Phillips, *Ore Deposits*, p. 3; Whitney, *Metallic Wealth of the United States*, p. 34; Newberry, *School of Mines Quarterly*, 1880, p. 337; Raymond, *Mining Statistics* for 1870, p. 448; Pumpelly, Johnson's *Cyclopedia*, 1886, VI., p. 22; Geikie, *Text-Book of Geology*, p. 589; Le Conte, *American Journal of Science*, Vol. XXVI., 1883, p. 17; Le Conte, *Elements of Geology*, p. 234; Emmons, U. S. Geol. Survey, Monograph, XII., p. 368. Classifications of ore deposits are also found in the German text-books of Von Cotta, Grimm, Serlo-Lottner, and Von Groddeck. Since this went to press a comparison of the various classifications has been published in Kemp's valuable treatise on *Ore Deposits of the United States*, pp. 42-65. This author also presents a classification of his own.

greater or less quantities, though not in sufficient abundance to be classed as ore deposits without the intervention of some agent of concentration. The other subdivision of eruptive deposits, the massive, is almost equally unimportant. There is no deposit of ore, known to be of eruptive origin, which is at present worked, although the deposit of native iron in Greenland, occurring in a basalt, is sufficiently rich to pay for extraction, provided its location was more favourable. This group may therefore be dismissed, its only importance being as a source of metalliferous substances for concentration under other conditions.

II. Mechanical Deposits (Figs. 16 and 17).—When a rock containing metals is disintegrated by weathering, the products of disintegration go off, partly in solution, partly as mechanical sediment. It is chiefly in this manner that disseminated deposits become introduced into sedimentary rocks. Usually metalliferous minerals are easily decomposed, and frequently, as a result of their decomposition, soluble salts are produced, or a very fine powder of hydrated and oxidized ore, which may be disseminated through fine-grained rocks. When, however, the mineral is comparatively indestructible, as in the case of gold, platinum, and oxide of tin, it outlasts many of the other minerals of the disintegrating rock, and may become concentrated. Where the chemical durability is combined with mechanical strength, as in gold, which is not brittle and not easily worn down, this concentration is favoured; but under ordinary circumstances this would hardly attain economic importance, were it not for the high specific gravity of some of this class of minerals. Gold, for instance, is disseminated through certain rocks, but in such small quantities that by their mere

decay, without the assorting action of water, it would hardly be accumulated. Given, however, a rapid stream, the lighter minerals are carried off, while the heavy gold accumulates in pockets where the currents are less rapid. Such deposits are of the mechanical type, including not only the accumulations in stream gravels, but also those in talus deposits and those which more rarely accumulate along shore lines, where conditions are favourable. When the three metals, tin, platinum, and gold, are excluded, this class of metalliferous deposits becomes unimportant.

III. Chemical Deposits. — This group of ore deposits includes all which come into their place by chemical action, and in it are included the vast majority of metalliferous deposits. There are a number of ways in which this form of mineral concentration is brought about, all of which, with the exception of some of the contact deposits, are caused by the intervention of water.

(a) *Precipitated Deposits.* — Precipitated deposits, in the sense used here, include those which are formed by precipitation from solution, at the surface, when the liquid which carries the minerals loses its power to hold them, either as the result of the loss of some of its properties, or by the accession of some substance which causes a precipitation. The simplest illustration of this class of mineral deposits is that of bog iron ore, where water which has carried in solution the hydrated sesquioxide of iron, obtained from the soil or the rocks, is, in the presence of certain vegetable acids, unable to maintain the solution, and the ore is precipitated frequently in a bog. Moderately extensive beds of impure iron are thus sometimes formed, and, being buried beneath other strata, become truly bedded deposits (Fig. 5).

Practically the same class of deposit is formed about an iron spring, where the iron-bearing water, rising from the earth to the surface, loses some of its gases, and hence some of its power as a solvent, and is forced to deposit the iron about the spring. Applied to non-metalliferous minerals, the process finds illustration in the stalactites of caverns and the siliceous sinter about hot springs. In some cases true veins illustrate very nearly the same principle; but probably other

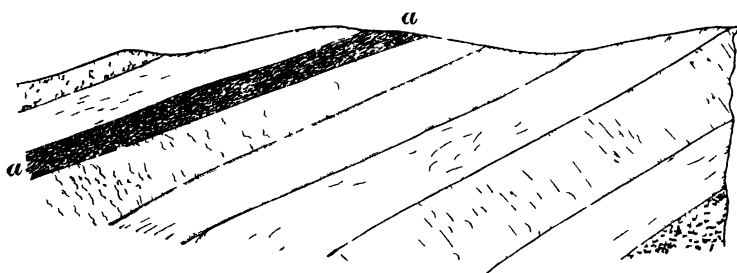


FIG. 5. — Bedded deposit of iron (a)

causes enter, and this group is so distinct in form and character that they will not be classed here.

(b) *True Veins*.—The term *true veins* is here given to those occupying pre-existing cavities where the mineral deposits have been placed by the agency of water. That percolating water is constantly active in its effort to fill cavities is shown by the study of fossils, such as Ammonites (shells allied to the chambered Nautilus of the present), where the chambers are filled with calcite, or silica, or even ores. The same is true of the gas cavities in lava flows, where geodes or amygdulæ are formed from the wall of the cavity toward the centre. The term true vein applied to such deposits is perhaps a trifle irregular, although there is no genetic difference between deposits from water in small

cavities and those in the type of the true veins, — the extensive fissure veins.

i. *Chamber Deposits* (Figs. 21 and 23), or cave deposits, are closely allied to these small cavity deposits. Here the source of the mineral is usually local, often from the same stratum in which it is accumulated. The process is allied to segregation, excepting that a cavity furnishes a place for accumulation. On the other hand, some chamber deposits are so nearly allied to precipitated deposits that they might very well be classed in that group. Stalactites furnish instances of this form of accumulation, and in some of the chamber deposits true stalactites of ore are formed.

ii. *Gash Veins* (Figs. 20 and 21) are comparatively rare and very local. The rock is cracked and spread apart, forming a local fissure, usually confined to one layer or stratum; and in these, as in the chamber deposits, the

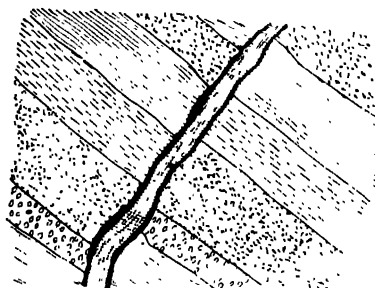


FIG. 6. — Fault plane occupied by a vein
— a true fissure vein.

supply of ore is evidently local. Both chamber deposits and gash veins are illustrated in the lead-zinc mines of the Mississippi Valley.

iii. *Fissure Veins*. — The type of fissure veins (Fig. 6) is perhaps the most common of all veins. The distinguishing feature of such accumulations is that they occur in a fault or fissure in the earth. Such veins are frequently of great extent both vertically and horizontally, but their width is relatively small. Usually the bounding walls are distinct, although sometimes they are crushed and penetrated by

the vein-forming mineral; or the solid wall may be impregnated by the ore (as described below), either of which conditions tends to make the bounding wall indistinct. There is in these veins evidence enough, in many cases, to prove that the mineral deposits came from water which passed through the vein, apparently from below upwards. This evidence is present in the banding of the minerals forming the vein, the same minerals being found in succession on each side of the centre. That is, if quartz is found next to the country rock on one side, this mineral is found in the same position on the opposite side; and if copper pyrite is found next to this on one side, it is present in the same position on the opposite side.¹ This banding is often very complex, and at times the cavity is completely filled, while in other veins the process of deposition was interrupted before the filling was complete.

It is possible to explain this process satisfactorily by assuming that heated water, either acidic or alkaline, was escaping from the heated parts of the earth's crust toward the cooler surface portions, and that as the water rose it lost in heat, and perhaps also in its acid or alkaline contents, and hence in its power as a solvent. Deposition from a supersaturated solution might then be made necessary. Under uniform conditions of temperature and foreign contents there would be a uniformity of deposit at a given place; and in proceeding from below upwards there would be a progressive change in the character or amount of deposit. A slight change, either a loss or an accession of heat or of contained substances, would bring about a change in deposit at different parts of the vein. These changes might occur vertically at the same time as the water ascended and lost heat, or

¹ See Fig. 12, p. 98.

horizontally at different times as the conditions at a given point changed. It is highly probable that some of the hot springs which are found in various parts of the country are the points of escape of metalliferous-bearing waters which are at present engaged in the formation of mineral veins.¹

There are certain peculiarities, found at times, not only in fissure veins, but in other mineral deposits as well, which call for a modification of this general statement. The vertical variations in the character of the ore are not always those which can be accounted for by the mere vertical change in the character of the ore-bearing solution, but in some cases these changes are apparently due to the influence of the surrounding rock. This has led to the theory that mineral veins are, in some cases, either supplied with mineral, partly or wholly from the enclosing rock, by lateral secretion,² or that by some electrical influence the character of the ore deposit is modified by the presence of some particular rock. It seems probable that both of these processes act, but that the chief cause of these mineral veins is the ascension of ore-bearing water from below and the deposition of the mineral without the intervention of these outside agents.

iv. *Ore Channels* is a term given to those planes of weakness which exist between two series of rocks, either between two eruptive rocks, or an eruptive and sedimentary or metamorphic rock, or along the unconformable contact of two

¹ A definite instance of this process is found at the Sulphur Bank Quick-silver Mine in California (see chapter on Mercury).

² Sandberger's experiments on the metalliferous contents of common rocks (described above, p 73) have given much support to the theory of lateral secretion. These experiments have proved that these sources *may* supply ore, and have made it probable that they sometimes do, but the proofs are not sufficient to warrant the widespread application given the theory by some.

series of sedimentary strata. These planes furnish channel-ways for the comparatively easy escape of subterranean waters. The remarks made in speaking of the fissure veins hold almost equally for these, excepting that the water is less liable to come from great depths, the channel-way is less distinct, and the influences which bring about deposit are more apt to resemble those of the more superficial deposits, such as those in chambers. It must, however, be borne in mind that even at shallow depths the earth may be highly heated by the intrusion of igneous rocks, and hence a supply of heat be furnished to subterranean water channels of comparatively superficial origin.

(c) *Replacement Deposits*.—Certain minerals seem particularly liable to solution and replacement by a gradual

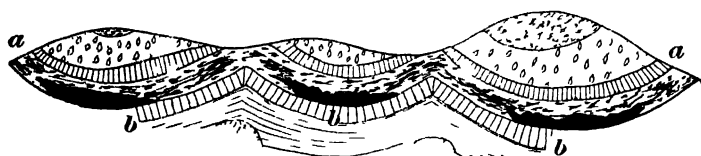


FIG. 7. — Bed of limestone, (a) being replaced by iron, particularly in the synclinal troughs, b, b, b.

molecular transfer, after the manner of petrification of wood. Under the proper conditions, this process may take place in any mineral; but the mineral calcite seems particularly susceptible to the change. In the rocks, fossils are thus replaced by a great variety of minerals (silica, iron, copper, and many others), one molecule being dissolved by the percolating water, while another is put in its place, until the transfer is either complete, or is in some way interrupted. By this process of replacement entire beds of limestone are sometimes dissolved away, and one of the oxides of iron put in their place (Figs. 7 and 15). Other minerals are acted

upon in the same way, and pseudomorphs — that is, a mineral of one kind with the form of another — are not uncommon in nature.

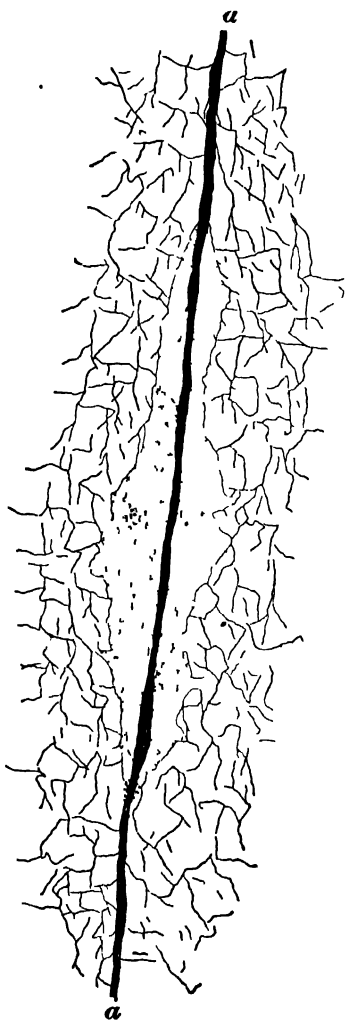


FIG. 8 — Impregnation of tin ore at East Hull Lovell in Cornwall. *a, a*, leader or divider. (After Phillips)

(*d*) *Impregnation Deposits* (Fig. 8).— During the formation of fissure veins, and indeed of other veins as well, it frequently happens that the ore-bearing solutions enter the vein walls and impregnate them with metalliferous deposits. These are at times replacements of pre-existing minerals, and at times the result of an accumulation of the foreign ore between the minerals of the country rock. Impregnation deposits, therefore, even in the same vein, may be of several kinds of origin: they may be concretionary, or replacement, and their source may be from the solutions which are filling the veins, or perhaps they may even be the result of a lateral secretion from the country rock toward the vein. They do not form important deposits by themselves, but are usually a leaner part of a true mineral vein.

A form of mineral deposit

known as Stockwerk possibly belongs here. It is found in the Cornwall district, and is typically a series of small ramifying veins and irregular bunches of ore, sometimes connected with fissure veins, but very frequently separate.

(e) *Concretionary Deposits* (Fig. 9). — It is easy to understand how deposits of ore accumulate in gravels, and in what manner minerals are chemically precipitated. The process of replacement is analogous to well-known phenomena, and the formation of mineral deposits in pre-existing cavities presents no inexplicable phenomena, or, at least, we are able to form a conception of their method of origin; but the two

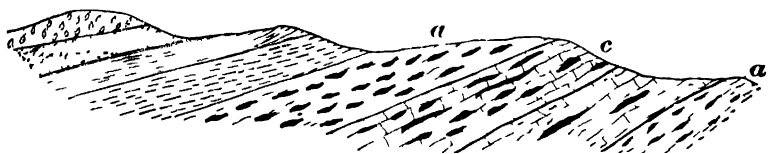


FIG. 9. — Concretions in strata *a, a*, iron-stone concretions in shale, *c*, flint concretions in limestone.

groups of deposits included under the headings concretionary and segregated are much less easily understood.

A study of the chalk beds of England shows that there are nodules and layers of flint which have been formed by the accumulation of silica, originally disseminated through the chalk, but now gathered together about a common centre, or along a common line or plane, and a similar condition exists in many beds of limestone. In slates, originally deposits of clay or fine-grained fragments of disintegrated rocks, it is not uncommon to find crystals, and bunches of crystals, of iron pyrite, which have been formed by the gathering together of the sulphide of iron from the surrounding dense rock, and its concentration where there was no pre-existing cavity. The iron-bearing clay rocks frequently

contain concretions of limonite, or of hematite of the same origin. How does this happen? By what force are particles of like nature drawn together from a given area to a growing concretion, forming a space for itself often in a compact rock? These are questions which the author has never seen explained in a satisfactory manner.

(f) *Segregated Deposits* (Fig. 10).—If it is difficult to answer these questions in the case of concretions, it is still

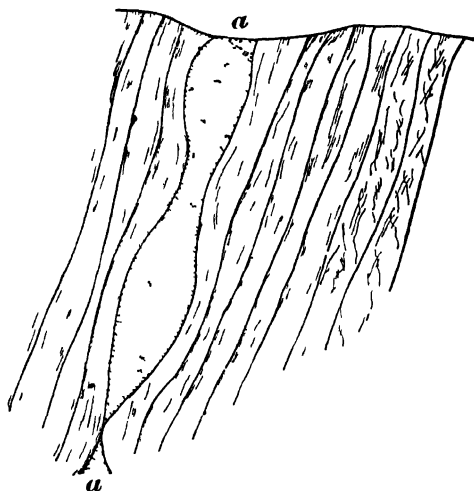


FIG 10 — Segregation of iron (a) in schistose strata.

more difficult to answer them when asked about the formation of the much more extensive segregated deposits. These occur most commonly as veins, often of considerable extent, though usually small and non-continuous, one beginning and fraying out, while another starts in the same general direction as if it were a non-continuous extension of the first. Sometimes they seem to have started in small cavities, or along planes of weakness; but with even greater fre-

quency, the entire space which they occupy seems to have been formed by the growing accumulation. They are generally parallel with the bedding or structural planes of the rock.

Segregated deposits occur most commonly in metamorphic rocks and, indeed, much of the metamorphism of strata seems to consist in segregation. Starting, let us say, with a clay rock of complex composition, the resultant of the decay of feldspar and hornblende, pressure and heat begin to act, and this, with the aid of the enclosed water, commences an alteration of the rock. The old decayed minerals commence to assume a more permanent and definite chemical composition and, indeed, to revert to their original composition. New feldspars and hornblendes and iron oxides are formed, and these different minerals by metamorphism tend, in many cases, to arrange themselves in bands which are at right angles to the direction of pressure. Actual melting does not take place, the new minerals are slowly evolved, and, as they develop minerals of the same kind, tend to form in clusters; in this case, in linear clusters. Thus, bands of hornblende, of iron, and of feldspar are formed, rarely strictly pure, but tending toward purity.

How far segregation accounts for ores it is difficult to say. Some ascribe to this process a very great importance, while others are inclined to consider it of minor importance; and it is true that the evidence of segregation is often obscure. Nevertheless it is a cause, and an important cause, particularly in metamorphic rocks. In sedimentary strata, it rarely expresses itself in any other form than that of concretion, and in unmetamorphosed igneous rocks the tendency to segregate is shown in the banding of minerals, and in the spherulitic concretions in lavas.

When asked what segregation is, one can answer only that it is a force which causes like minerals to gather together, and is merely another form of concretion. We know that, by some form of attraction, molecules of a given substance will accumulate to form a mineral crystal, each particle that can be drawn to the crystal being added to it. There is here certainly some attractive force — “chemical affinity.” In segregation, perhaps, the same force is at work. Its attractive power is strong, for it draws material from considerable distances; and, once started, its force seems to be increased until a neighbouring area is leached of all the desired mineral that is in a form admitting of transfer. Heated water seems to increase the tendency, and the initial presence of cavities appears frequently to give an opportunity for a beginning, though by no means is this a necessary starting-point. In true mineral veins, the same tendency of accumulation is shown under more favourable circumstances of supply and opportunity. What the attractive force is cannot be told. It is a force, and it acts in the above manner, and we therefore have a name and a definition, which is perhaps as satisfactory as if we attempted to assign it to a place among some of the slightly understood forces of nature. It might be called an electro-chemical process, as indeed it has been, and, in spite of denials, this seems still a not unreasonable explanation.

(g) *Contact Deposits* (Fig. 11). — By the contact of igneous rocks, highly heated and molten, the surrounding layers may be markedly modified, particularly when large masses or bosses of igneous rocks are intruded at considerable depths. Such masses take many years, probably centuries, to cool, and during all this time they are tending to alter the

surrounding rocks, not alone by their heat, but chiefly by the aid of the aqueous vapour or superheated water, which is present in abundance in all lavas. A zone of contact metamorphism is thus produced, in which to a distance of many yards the surrounding rocks are often altered past recognition, by the development of new minerals both from the material in the country rock and from the gases furnished by the lava.

In such positions mineral deposits formed in several different ways are not uncommon. By sublimation, as in the

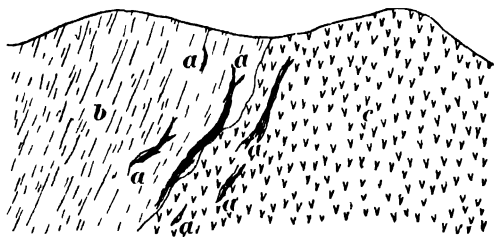


FIG. 11. — Contact deposits (a), between and in shale (b), and diabase (c).

case of mercury and sulphur, mineral deposit; may be formed at or near the contact as the result of condensation, from the gaseous condition of substances emanating from the igneous rock. More commonly the presence of the lava serves to concentrate minerals along the contact, partly from the igneous, partly from the cold enclosing rock, by a process of segregation. All deposits along the contact of igneous rocks must not, however, be considered as contact deposits; for, by a subsequent process of segregation or concentration, mineral veins may be formed along these lines of weakness by the solution of the ore contained in the igneous or in the country rock and its deposition here. This

is the origin of a great many of the apparent contact deposits; but, nevertheless, true contact veins, both of concentration and sublimation origin, actually exist.

Distribution of Ore Deposits. — It will be noticed in studying the distribution of ore deposits in any country that they are more common in certain parts of the region than in others, and this is the direct result of cause and effect. Omitting the mechanical deposits which may occur in any place where the supply of ore is sufficient and the conditions of weathering and deposition favourable, the precipitated deposits which may also occur anywhere, segregated and replacement veins which are typical of metamorphic or the older sedimentary rocks, and the only important groups of mineral deposits remaining are the true and contact veins which include by far the greater number of mineral deposits, if iron, manganese, and stream-gold are excluded.

These two groups of metalliferous veins are associated in origin with either cavities or heat, or both combined. Geographically they are associated most commonly with mountains, and usually with mountains of recent formation. The reason is apparent, for in such places there are numerous fractures and fault planes, and abundant volcanic and intrusive igneous rocks, — in fact, all the conditions necessary for the formation of such deposits. Moreover, in high mountains erosion has penetrated to considerable depths, and hence has revealed to us more of the hidden stores of the earth's crust.

Geologically, in this country the mineral wealth is chiefly stored in the less ancient rocks; that is, in post-Archean series, and in many cases in post-Palæozoic strata. This is due largely to the fact that these rocks form the greater part

of the recent mountains of the Cordilleras. One might consider it remarkable that the older strata, which have for a longer time been exposed to the action of subterranean water and other agents of change should be comparatively so unimportant as mineral producers. There seem to be at least two probable causes for this. In the first place, the lower rocks being buried beneath a great thickness of overlying strata, when subjected to mountain-forming forces tend to fold rather than to break, while the less compressed layers nearer the surface become more fractured. Fewer cavities, therefore, exist in these older rocks. Besides this these deeply buried strata are subjected for long periods of time to a leaching of percolating waters which escape toward the surface and deposit their dissolved mineral in the cavities of the overlying strata. They are robbed of their mineral contents for the benefit of the overlying layers. If this be true, then in older mountains, such as those of New England, there may have formerly existed mineral deposits which have since been destroyed by erosion. The discrepancy between the Appalachians and Cordilleras is also, as has already been stated, due to the conditions prevailing during their formation. Thus the Appalachians seem to have been formed more by folding and less by faulting than the Rockies; and, also, the former were practically without volcanic activity, whereas in the Cordilleras volcanic conditions were marvellously developed. These differences seem sufficient to account for the marked difference in distribution of ore deposits in this and in other countries, showing the intimate relation which exists between geologic conditions and mineral wealth.

CHAPTER V.

MINING TERMS AND METHODS.¹

Mining Terms. — A *mineral* may be defined as an inorganic substance having theoretically a definite chemical composition and frequently a definite geometric form. It is usually a combination of elements, though sometimes a single element, as gold, sulphur, etc. Miners use the term *mineral* as a synonym of *ore*, which is, according to the economic standpoint, a metal, usually mineralized, occurring in sufficient quantities and in such combinations as to be economically valuable.

Elements are of two kinds, *metals* and *metalloids*, though some have properties common to both groups, and the distinction is much less sharp than was at one time supposed, before all the elements were carefully studied. The typical metal has certain definite characteristics, being basic rather than acid in its properties, having a considerable specific gravity and a metallic lustre. In the arts the metals serve different purposes, depending upon their physical characters, some being bright, beautiful, and not easily tarnished; some

¹ That part of this chapter which refers to mining methods is necessarily brief and generalized, and refers only to the more important processes. There are text-books which give in detail information upon this subject; but the only way in which such knowledge is properly obtained is by a study of the mines themselves. A good short account of mining terms and methods will be found in the last part of Davies, *Metalliferous Minerals and Mining*, and other treatises are referred to in the list of books of reference at the close of this work.

having hardness, or ductility, or malleability, or a low or high melting-point, etc. The metals which we know best, such as gold, silver, iron, copper, etc., are, with the exception of iron, comparatively rare, while the most common metals, such as aluminum, calcium, magnesium, etc., are comparatively rare in the arts. Of the metalloids, oxygen, silicon, and carbon are the most common.

As has already been stated, these elements combine in different proportions to produce minerals, some of which are ores. In the mineral vein there are not only ores, but also very frequently foreign minerals which make the *veinstone* or *gangue*, a foreign, mechanical mixture of minerals which are of no economic value. Thus, not only are calcite and quartz considered to be gangue, but also such metalliferous minerals as iron pyrite, which have to be separated from the ore by mechanical processes. When minerals combine to form a fixed and essential part of the earth's crust, a *rock* is formed, and these may result from crystallization by metamorphism, or from solution, or from a molten condition, or they may be produced by the mechanical destruction of pre-existing rocks and the accumulation of the fragments. Ordinarily the term *rock* is applied to a *solidified* accumulation of minerals, but in reality it should be made to include unconsolidated deposits as well, since there is every gradation between the unconsolidated and solidified sometimes in the same bed. There is some difference of opinion as to the propriety of including veinstones under the term rock; but it seems better to consider them as minerals, although miners sometimes speak of the veinstone as vein-rock.

A vein, as well as a rock, is said to *outcrop* where it appears at the surface in a natural exposure,—or where

it crops out. In California the outcrop of a vein is frequently called a *ledge*, since the outcrops for which the prospectors of that region were most anxiously looking, being of hard quartz, formed a ledge. For the same reason, the term *reef* is used in Australia, this name being suggested, no doubt, by the resemblance to the coral reefs of that region, which project above the ocean. Instead of a ledge-

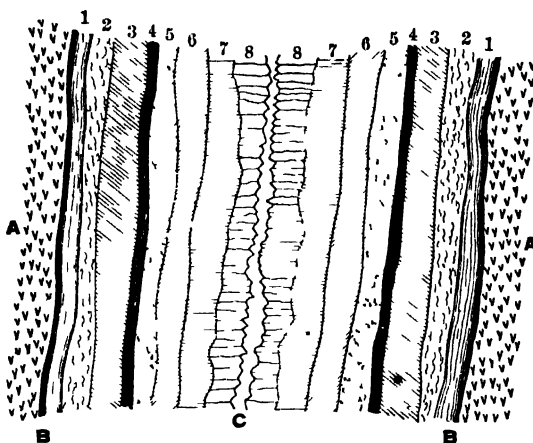


FIG 12 — Section of mineral vein showing ribbon or banded structure and symmetrical disposition of the various mineral bands A, country rock, B, fluccan, C, comb structure, 1, iron pyrite, 2, calcite, 3, quartz, 4, magnetite, 5, barite, 6, chalcopyrite, 7, galena, 8, quartz.

like outcrop, it is more common for many mineral veins to be marked by a depression caused by the weakness of the ore or the gangue, or both. In such cases the ore is often hidden and discovered by accident, though its position may be indicated by loose boulders, or by a stain or rust characteristic of the metal. The Cornish miner calls this *gossan*, while in France and Germany it is called the *iron hat*,¹ because of the characteristic iron stain. For a vein the term *lode* is sometimes used meaning a deposit which the miners are following

¹ *Chapeau de fer* and *eisener Hut*.

in the expectation of finding something valuable,—the deposit which is leading them, hence sometimes called a *lead*.

In the vein, one of the most striking features, provided it is a true fissure vein, is the *banded structure* (Fig. 12), due to the regular arrangement of the various layers on either side of the centre. At times the vein is completely filled; but it is frequently the case that it is only partly filled, and the projecting points of the crystals last formed produce a serrated surface known as the *comb structure* (Fig. 12). Fragments of foreign rock, included in the vein, are called *horses* or *riders* (Fig. 13), and these are usually broken from the neighbouring or enclosing *country rock* or *country* (Fig. 12 and 13), though sometimes they are included between two veins. The country rock

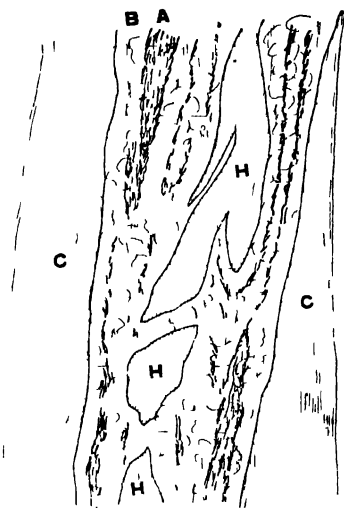


FIG. 13 — Vein of blende and galena (A) in a gangue of quartz and calcite (B), including horses (H) of the country rock (C) (From Davies.)

is sometimes sharply defined, forming the *vein wall*; and since nearly all veins are more or less inclined, the two walls are called respectively *hanging* and *foot walls* (Fig. 14), according as they are overhead or beneath the feet. Between the vein and the country rock there is frequently a clayey substance, *clay selvage*, *fluecan*,¹ or *gouge*

¹ This, like many of our mining terms, is a Cornish name, for from this district we have obtained not only many of our mining methods, but also much of our mining nomenclature.

(Fig. 12), which is sometimes the result of decay, sometimes of faulting and crushing by a movement between the vein and wall. It is of value in mining, because it is easily removed, it enlarges the vein, gives a smooth firm wall, and is, moreover, a good sign, since it is more common in fissure veins than elsewhere, and such veins are more liable to be permanent. By this subsequent movement in the vein the walls, and even the different parts of the vein, are often polished and grooved or *slickensided*. A careful study of slickensides frequently shows where to look for the continuation of a vein which has been lost by being moved out of position by a cross-fault. During the formation of the fissure in which the vein is located the country rock is sometimes crushed and brecciated, and during the formation of the vein these fragments may be cemented by either gangue or ore. Subsequent movements may again open the vein, either causing a new fissure or crushing the vein-rock to a breccia.

The horizontal direction of the vein is called its *strike*, or by miners very frequently the *run* or *course*. Veins rarely extend vertically into the ground, but generally *dip* or *hade* at a greater or less angle. In geology, the dip is measured in degrees from the horizontal; but in some mining districts it is measured from the vertical, the one being then the complement of the other. In some of the English districts this angle is called the *underlie*. Besides the dip there is sometimes present a *pitch*, a term which refers to a dip of the entire vein or pocket in the direction of the strike. The relation of the ore to the surrounding rock, together with the strike, dip, and position of the vein, is shown by means of various plans and sections. A *geological map* gives in

horizontal plan the various rocks which enclose the vein; and if it is desired to show the horizontal appearance of the vein, or of its tunnels at different depths, *ground plans* are made to show these features. Where it is desired to show the linear extent of the vein and of its tunnels, and the position of the shafts, a *longitudinal section* or plan is made parallel with the plane of the vein. A *cross-section* is one made at right angles to the strike of the vein, and shows its dip, the position of the enclosing walls, and also the position of the shafts and tunnels in the line of the section. The geological map and the cross-section show most clearly the geological structure, but the ground plan and longitudinal section are the most valuable in showing the position and number of the tunnels.

Variation in Veins. — During the process of mining there are often found to be variations in the character or position of the ore. The vein varies in width, *swelling* and *pinching*, sometimes by original irregularities, at times as the result of an actual squeezing in of certain parts of the vein, forming alternate pinches and swells. The walls *roll*, the miners say, since they seem to form waves. Actual faulting may cut off the vein, and the miner finds the ore ending abruptly against a wall of barren rock. These faults are sometimes of small extent, in which case the vein is readily found again; but in some cases valuable veins are completely lost. In a given district veins have a prevaillingly uniform direction, frequently parallel to the direction of the strike of the rocks or of the mountain range. Yet, on the other hand, they may be very irregular in direction, and in the same district two or more sets of veins may exist. In such cases the veins of one set are usually richer than those of another, and they

may be widely different in character, one set being perhaps barren of ore. These veins frequently intersect, the older being crossed by the younger, and being displaced by the disturbance which formed the vein cavity. A great variety of confusing conditions are encountered by miners in consequence of these intersections of veins; but a careful study of the geology of the district will usually aid in the solution of the problems thus presented. On the other hand, veins are frequently lost by becoming gradually more and more barren, or sometimes by branching at either end, and thus becoming smaller and more difficult to work, and in these cases the ore is usually permanently lost. From the main vein branch-veins are frequently sent off, and these are called *droppers* or *feeders*, the latter name being given because they are supposed to furnish the vein material, though in reality these offshoots diminish the quantity of mineral in the vein.

The ore often varies both in quantity and quality in different parts of the same vein. This variation may occur even in the same enclosing walls, or it may at times be dependent upon a change in the character of the country rock showing the influence of the enclosing rocks upon the vein material. The variation may amount to a complete change in the kind of ore as in the Przibram district of Bohemia, and in Cornwall, where the influence of the rock is very marked, the ore sometimes changing from copper to tin. Change in the character of the ore in a vein is, however, most commonly the result of an alteration due to the effect of weathering. Below a certain line in the earth there is permanent water, the rocks being saturated. This *water line* varies greatly in position according to the climate, being in some parts of the arid regions many hundred feet beneath

the surface. Above this line the minerals are subjected to conditions of alternation from dry to moist, and consequently if they are not permanent combinations, to changes in character. Most ores are comparatively unstable, and under these conditions are altered in composition. Thus galena, the sulphide of lead, becomes altered above the water line to the sulphate anglesite, and many sulphides become carbonates, or oxides, usually of hydrous varieties. Moreover, by the solvent power of the percolating water metallic salts may be dissolved and carried away leaving the ore above the water line more porous. The effect which these alterations have upon the richness of the ore is very different under different conditions. Thus the native gold of California is found enclosed in iron pyrite in quartz rock, but by weathering the iron pyrite is removed, and it was supposed in the early days of the mining industry of California, that the gold became less abundant as the depth of the mine increased; but with the present methods the gold is easily extracted from the pyrite. On the other hand, instead of carrying away the gangue in solution, the percolating water may destroy the ore and thus make the vein above the water line less rich. This, however, is often more than compensated for by the increased difficulty of mining or reducing the unweathered ore from below the water line. For different ores and gangues and for different climates the conditions of weathering vary so that no general statement can be made, but each district may have a peculiarity of its own.

Mining Methods.—In order to obtain a metal, there are usually four processes which must be used,—mining, dressing, concentration, and reduction. The first three processes are

mechanical, the fourth depends upon chemical reactions. In mining, the first step is naturally to find the vein, and for this, very different methods are in use in different parts of the world and for different kinds of ore. The Cornish miners speak of *shoding*, shodes being fragments of veins increasing in size as their source is approached; and shoding consists in tracing these fragments to their source. American miners have invented for this process of ore-finding the term *prospecting*, a prospector being one who is in search of a prospect upon which to base future work. At the time of the development of the gold fields of California in the years succeeding 1848, a horde of people of all classes turned prospectors, and even at present there are thousands of such people in the Cordilleran region, now, as then, for the most part barely eking out a living, though ever in hope of finding some prospect which shall yield them a fortune, as some of their numbers have already done, in some cases several times.

The original prospector confined his attention to the streams, washing the gravels here and there, in search of placer deposits. When this field became fully occupied and less paying, the attention of many of the prospectors was turned to other deposits, and these men have, in many cases, developed a wonderful degree of skill in the detection of ore deposits,—a skill which the trained mining engineer may well covet. Their methods consist chiefly in the application of a wide experience, by which they are able to tell where *not* to look for ore, and what is the surface appearance of various common metalliferous deposits. The characteristic rust of a metal, as the green of copper, or the yellow of lead, the crumbly, disintegrated appearance of the outcrop of an

ore, and the appearance of characteristic vein minerals, all serve as guides. More scientific methods, which are sometimes possible, the prospector does not usually possess; but the vast majority of mines in the west have been discovered either by pure chance or by the application of these methods.

Having found a surface indication of ore, the next step is to *develop* in order to see if there is a "show," and if so, to give the property a market value. If the outcrop is not already fully revealed, enough work is done to see in which direction the vein strikes; and then, in order to test its extent, *cross-cuts* are made at right angles to the strike, the earth being removed down to the bed rock until the vein is encountered, and this is continued at intervals of a few yards until the miner is convinced of the probable direction and extent of the vein. Since most of the newly discovered ore deposits in the west are situated upon government land, the miner must then *locate* his claim at a government land office, and then, within a specified time, do a sufficient amount of work to become the absolute owner of the land. If the deposit is of much value, it is usually not long before others have located claims near by, and the whole region is crossed by these claims, often in such inextricable confusion that long-continued litigation results, and the profits of the mining operations are diverted.

Subsequent development depends largely upon the local conditions, the character and position of the ore primarily, as well as the probable future of the mine. The immediate purposes, or even, in some cases, the permanent development, of the mine may be best served by opening the deposit as a pit or as a quarry, although the most common method is to open a *mine*, or a series of shafts and tunnels. In the

serious development of a mine, the most important thing to be taken into consideration is drainage, and this gives to miners more trouble than any other single need. The simplest possible condition is to commence the mine upon a

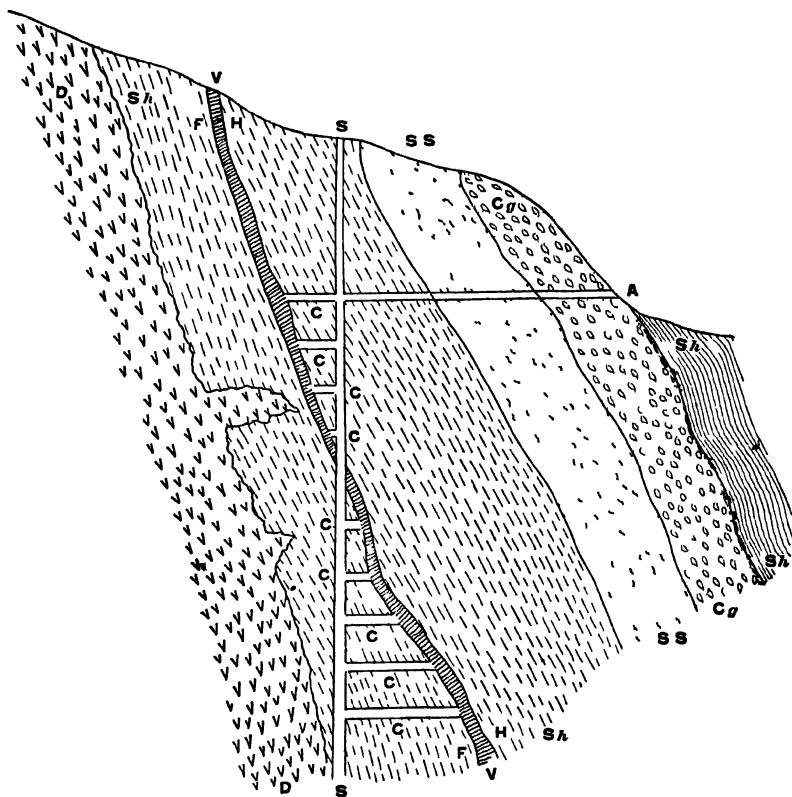


FIG 14 — Diagram showing usual method of exploiting a vein. *V*, vein or lode, *H*, hanging wall, *F*, foot wall, *D*, intrusive diabase, *Sh*, shale, *SS*, sandstone, *Cg*, conglomerate, *S*, shaft, *A*, adit level, *C, C, C*, cross-cuts

valley side, and drain it into the valley, as the work of development progresses, using the lowest tunnel for a drainage way. Where this is impossible, it is frequently found economical to extend a *horizontal shaft, tunnel, drive,*

or *adit level* (Fig. 14), as it is variously called, to some neighbouring valley, and this is often done at an immense expense, the expenditure of years in construction, and the formation of a tunnel sometimes several miles in extent.¹ When this is impossible or impracticable, pumping is resorted to, but this is an extremely expensive process in deep mines.

When the vein is vertical, a shaft may be sunk in the vein and the material removed made to pay the expense of construction; but most veins are inclined, and then one of two things is possible, — either to work on the incline and hoist the ore on inclined tracks, or to construct a vertical shaft which shall intersect the vein at a considerable depth and be connected with it by a number of short horizontal tunnels; and in well-developed mines this is usually done. The width of the shafts and tunnels varies with the amount of work to be done. In working along the vein or lode, horizontal tunnels or “drifts” are made through which the ore is hauled to the shafts, where it is hoisted to the surface. Usually there is more than one shaft, often a number, connecting different levels or drifts, these being used partly for hoisting ore, partly for ventilation (“winzes”), which every well-developed mine must take into account. From the drifts and small shafts the ore is worked or “stoped” out, sometimes by overhand, sometimes by underhand, stoping; that is, from above or below. In this stoping, secondary drifts and partial shafts (“mills”) are constructed to facilitate the process of ore extraction.

During the process of mining the lode is completely horrey-

¹ The Sutro Tunnel of the Comstock Lode in Nevada is 20,489 feet in length, and meets the Lode at a depth of 1900 feet. Its cost was \$2,000,000.

combed by these various excavations.¹ In old-fashioned or in poorly developed modern mines, the excavations are irregular and the tunnels rudely constructed, being confessedly temporary; and when one part of the mine is worked out, it is abandoned to its fate. Where better and more permanent methods are used, pillars of ore are left to support the roofs of the tunnels, and the shafts and tunnels are carefully timbered to prevent collapse. For this purpose, not only is much valuable ore left behind, but often millions of dollars are expended in timbering, particularly in some of the larger mines of the Cordilleras, where timber is scarce and difficult to obtain. This timber is a danger in one respect, since it is liable to be burned and cause a temporary abandonment of the mine as well as great expense in retimbering. During the development of the Comstock Lode, a novel difficulty was encountered which all large mines, extending to great depths into the earth, are liable to encounter in time. This is intense heat, which, in the Comstock, was encountered at a point unusually near the surface, owing, no doubt, to the proximity of heated rocks of igneous origin. Floods of hot water burst through the walls, and flooded the mine, heating the air so that work was well-nigh impossible. It was necessary to pump cold air into the galleries, and even then slight physical exertion was nearly impossible, so that eventually the lower tunnels of the mine had to be abandoned.

Excepting for the general direction of operations, the process of mining in itself is purely mechanical. One fundamental principle is followed, — to leave below as much of

¹ In 1880 there were more than one hundred and fifty miles of shafts and galleries in the Comstock Lode, and since then these have been somewhat increased.

the gangue as is possible. Hence each miner directs his labours so as to avoid barren areas, and, where possible, to make them serve as supporting pillars. The ore is drilled, blasted, or picked, according to its nature; and in selecting material to be sent to the surface, the fragments are roughly assorted in the mine in order to send out of the mine as little valueless mineral as need be. For transportation from the point of mining to the shaft, various methods are used, such as wheelbarrows, horse railroads, cable, gravity, or even, at present, electric roads. Having reached the shaft, it is hoisted to the surface by a method depending upon the scale of operations adopted in the mine, this varying from hand power to electricity.

The mines in Europe are frequently owned and operated by the government; but in this country they are in the hands of private owners, who usually direct all operations, although in some of the western mines a method of working known as the *tribute system* is in operation. Certain parts of the vein, and at times the entire mine, are turned over to individual miners or groups of miners to develop on shares. This method is usually adopted in mines where the amount of ore varies greatly, and where rich pockets occur in great areas of barren gangue, or in mines which have been abandoned because of the average poverty of the deposit. It is probable that the average result of this system is far from profitable to the miner, but the element of chance and the possible riches which are sometimes won is a sufficient incentive to many miners to enter into the tribute system. The owners risk very little, but this system is usually bad for a mine, since the tribute miners generally leave it in a bad condition, and not properly timbered or ventilated.

Concentration of Ores. — When the ore has arrived at the surface, the mechanical process is still farther pursued in separating the ore from the gangue. This is often done, first by breaking the fragments into smaller pieces, generally by hand, and then by the separation, also by hand, of the very lean ore and gangue from the richer fragments. The ore is now in a fairly concentrated condition, but is still in combination, mechanically with some of the gangue, and chemically with the mineralizer. The methods used for the extraction of the metal from these associations are extremely varied, depending both upon the character of the ore and the development of the mine. A few of the more important methods only are briefly described here.

The first thing to be done in gold-bearing quartz and some other ores is to crush the ore so that even the finest particles of foreign, mechanically associated mineral may be removed by water. This is done by means of the stamp, an apparatus so old that the time of its invention is not known. There are many kinds of these, the most improved being the piston stamps in which a heavy head, weighing in some cases a ton, is raised to a height of from twelve to fourteen inches and then dropped. In some of the better equipped mills not only do the piston stamps work automatically, but the ore is fed in the same manner, and one may pass through such a mill, where many stamps are at work, without seeing any other workmen than the watchmen.

In the placer gold, platinum, and stream-tin deposits nature has performed the duties of the stamp mill in disintegrating the rock which contained the ores; and to a certain extent, also, the duties of the concentrator by the assorting power of running water. This same principle is

made use of in much of the separation of ore from gangue. Placer miners separated the heavy gold from the admixture of gravel by means of a pan or some similar contrivance, simply giving to it a peculiar shaking motion which caused the heavy gold to accumulate in the bottom of the pan, while the lighter gravel was washed out. The introduction of the *cradle*, an inclined board with riffles, was an advance in method which was followed by the *sluice*, an apparatus in which nature's process of concentration is closely imitated. This consists of a long box with a rapid slope, built in the river valley, into which the gold-bearing gravel is washed by streams of water. The gravel rushes down through the box, while the heavy gold drags near the bottom and tends to collect behind the riffles, or cross-pieces nailed across the bottom of the box, just as it does in the streams where the current is slackened by a boulder or some other obstacle. Two things are necessary: a plentiful supply of water and a rapid slope. In some parts of this country, and of other countries as well, there are extensive deposits of gold-bearing gravel which might be worked by this hydraulic process, if water or slope were present. Indeed, in most of the placer regions of the west the water supply has presented difficult problems, for the solution of which vast sums of money have been expended in the construction of canals and water pipes for the carriage of water often from one drainage basin to another. Even under these circumstances hydraulic mining was very successful, and gravel with very little gold was worked over with profit.

In the case of gold-bearing quartz and other ores in which the gangue is abundant, the ore is crushed to a pulp or "slime," and under different circumstances different methods

are used for the separation. An ingenious contrivance for this purpose is the *pointed box*, an apparatus consisting of several V-shaped boxes of varying size with small apertures at the apices. A stream of water passes from one to the other, keeping the water in them in circulation, and "slime" is fed into the first box, the heavier parts sinking and passing out of the opening at the bottom, and the balance being carried into the next, where, the current being less strong, still more of the heavy particles drop through the aperture. Beneath each box there accumulates a pile of material; pure ore beneath the first, pure gangue ("tailings") beneath the last, and beneath the intermediate ones an admixture which may pay for further concentration.

Frame, tye, or buddle, are names given to an inclined board upon which crushed ore is fed, together with a current of water which carries the lighter material downward, while the ore remains near the top, and in the middle there is an admixture of ore and gangue which may need to be passed again over the frame. A man standing near with a rake assists the separation by stirring the slime. Machinery works faster, but produces no better results than this rather crude method. When jarred by machinery the frame becomes the *percussion table*, of which there are numerous modifications. A constantly moving belt of corrugated rubber, *the vanner*, upon which the ore is fed, serves to concentrate it in a similar manner. The *jij* or *jigger*, also used for this purpose, consists of a box with small holes in the bottom. Slime is placed in this, and a jiggling motion given to the box either by hand or by machinery (*piston jigger*), by which there is a separation of the minerals into layers according to specific gravity, the ore seeking the

bottom. One of these pieces of apparatus, or some modification of it, is used for nearly all ores where the percentage or character of the gangue is such as to call for a mechanical separation further than that of selection*at the mine. Some ores of iron and other metals are sufficiently rich when extracted to go directly to the smelter without concentration. Other ores are in such combinations, as, for instance, with some mineral easily disposed of in smelting, or with some heavy mineral which cannot be separated by water, that concentration is either not necessary or not possible.

Reduction of Ores. — For the chemical reduction of ores, a few words of the most general nature must suffice. Each different ore is treated in a different manner, but in general three methods are used: amalgamation, smelting (the dry way), and metallurgy (the wet way). The process of amalgamation is used chiefly for the extraction of gold and silver. In the case of gold it is used to remove the metal, which is mechanically mixed with impurities. Mercury placed in the sluices in hydraulic mines, remains behind the riffles and greedily seizes all gold which comes within its grasp, forming an amalgam with it. Practically the same is done with the gold extracted from the quartz rock by crushing and concentration. From the amalgam the mercury is easily driven off by heat, and, being collected by condensation, is ready to be used over again. For the extraction of gold from its silver and other alloys, finer methods are used. The affinity of mercury for other metals is also made use of as for instance in the extraction of silver from certain of its ores. Several processes are used, but in general they consist in the use of mercury, the crushed ore, and some salt, which are all stirred together, in the Mexican mines by driving mules back and forth over

the ore, but more commonly by machinery. A chemical reaction, not very well understood, takes place; the silver is freed from its chemical combination, and enters into an amalgam with the mercury, from which, as in the case of gold, it is obtained by heat. So important is the use of mercury in the extraction of gold and silver that the greater part of the supply of this metal is used for that purpose.

Ores differ very markedly in the strength of the affinity which binds the metal and mineralizer together. The chloride of silver can be extracted by a very gentle heat, the chlorine being driven off and pure silver left. With other ores a high heat does the same, and, again, by the use of some other mineral as a flux, upon the application of high heat the metal is driven from its mineralizer, which enters into combination with the flux, while the metal remains free. Some ores have to be smelted again and again, and some are so difficult to obtain that they are not mined. Every year adds to our knowledge of metallurgical processes, or gives us some new way of smelting by which it is possible to extract the refractory metals more economically. As an instance of this the Franklin Furnace zinc mine of New Jersey, originally worked for iron, is now kept open chiefly for the zinc. Formerly the zinc contained in the oxide zincite, the silicate willemite and the oxide of iron and zinc franklinite, was considered to be in too refractory combination for separation.

Before smelting some ores it is necessary to either calcine them—that is, to allow them to decompose in the air at ordinary temperatures—or to roast them. This serves to drive off a part of the sulphur, or arsenic, or other elements which have strong affinities for the metals. The ore is then

smelted and the metal obtained. For more detailed statements concerning the processes of smelting or of metallurgy, recourse should be had to some of the treatises upon the general subject, or upon special ores or metals.¹

¹ Some of these are referred to in the bibliography at the end of the book.

PART II.

METALLIFEROUS DEPOSITS.

CHAPTER VI.

IRON.¹

General Statement. — The ores of iron are, (1) *brown hematite* (including all varieties of the hydrated sesquioxide, — limonite, göthite, bog ores, etc.); (2) *red hematite* (the anhydrous sesquioxide, including specular, micaceous, fossil hematite, and other varieties based upon physical characteristics); (3) *magnetite*; and (4) the *carbonate* (FeCO_3 , including spathic ore, blackband, siderite, etc.). Native iron is found in meteorites and in basalt rock, in Greenland, but it is not known as an ore. The sulphide, iron pyrite, is mined, not for its iron, but for the sulphur which it contains.

An iron ore, in the present state of the iron industry, must occur in a very favourable position as regards market, it must be of good quality, in considerable quantity, and favourably situated for extraction and smelting. The presence of sulphur or phosphorus in an ore makes it valueless unless the quantity is very slight. Iron is now so cheap that, where mining operations are difficult, as, for instance, where the mine is deep, the vein narrow, gangue abundant, or transportation difficult, it cannot be mined. There are a sufficient number of good iron deposits in this country to make selection possible, and consequently many of the older mines are being abandoned because of the development of these

¹ A very complete account of the iron industry of this country is found in Vol. XV., Tenth Census, pp. 1-601.

more profitable mines. For reasons of this sort, the New Jersey region, for instance, which was once an important iron-producing section, is becoming abandoned; and whereas only a few years ago there were many score of profitable mines in that state, now there are very few. As this ore is chiefly magnetite, and some of it of a very high grade, it is possible that the use of electricity in the separation of the ore, which is now being experimented with, may revolutionize the iron industry of that state.

The most favourable situation of an iron ore for profitable extraction is near good coking coal for smelting and limestone for a flux, as in the Birmingham district of Alabama; and in such a situation even low-grade ores can be worked profitably. Unless this is the case, iron ore cannot be extensively mined excepting under conditions of great abundance and economical methods of transportation, as in the Lake Superior district, where thick and remarkably uniform beds of good ore occur in such a position that water transportation to the market is possible. Where these conditions do not exist, iron-mining is feasible only on a small scale for the local market. Thus, in the Rocky Mountains, there are almost inexhaustible supplies of iron, often of high grade, which are at present of no value whatsoever.

Brown Hematite Ores. — The brown hematite ore (hydrated sesquioxide), of which limonite is the most important variety, produced, in 1891, 18.9 per cent of the iron ore of the country. Of the total output of 14,591,178 tons of iron ore, 2,757,564 tons were of brown hematite. While in 1880 this ore was third in rank of importance, in 1891 it held second place in the production of iron.

Hydrated sesquioxide of iron occurs abundantly in most

soils as a yellow stain, and nearly all percolating water takes it into solution. From this it is frequently precipitated in bogs, forming bog-iron ore, which is common in New England and the northern states generally. Here it was mined in the last century and used for iron; but at present, partly because of its impurity, partly on account of its local nature, this source is not exploited. At present, the greater part of the supply of brown hematite comes from the southern states, chiefly from Virginia, Alabama, and Georgia, where it occurs typically as beds in the nearly horizontal sandstones of recent age and in the older slates and limestones. The first mode of occurrence is typically illustrated in the iron mines at New Birmingham, Cherokee County, Texas, where flat-topped hills of erosion, or "buttes," stand up above the surrounding country, and in these beds of iron occur capped and underlain by a partially consolidated ferruginous sandstone. The ore, which varies in colour from brown to black, and is usually granular or semi-compacted, is of the bog-iron variety, and is distinctly bedded with the sandstones, having apparently been precipitated in shallow lakes or lagoons along the shore line before the region was elevated in Tertiary times. After scraping away the loose or semi-compact sandstone covering, the ore is easily removed by picks, and the mine worked at a low cost as an open work or pit. There is much of this class of ore in eastern Texas and other parts of the Tertiary plain, although at present it is very slightly developed.

In northeastern Alabama brown hematite occurs in pockets, often of large size, from which it is extracted by means of a steam shovel. Pennsylvania is an important producer of this ore. In Lehigh County it occurs in slates,

apparently the result of the decomposition of pyrite, or else of concentration by deposition from percolating water. There is a more or less continuous band of limonite, often associated with manganese, in the limestone belt of early Palæozoic age which extends from Vermont to Alabama. Mines in this belt are located at Brandon, Vermont; Richmond, Massachusetts; Schuylkill County, Pennsylvania; Shenandoah valley, Virginia, and elsewhere. Whether originally precipitated or subsequently concentrated, perhaps by replacement, is still a disputed point. On the Pacific slope the most important iron-producing region is a limonite bed near Portland, Oregon. Here, in the Prosser mine, the limonite is found in hollows in a basaltic lava flow which has been buried beneath a later flow of lava. These hollows seem to have been lakes and swamps, as indicated by the association of tree trunks and vegetable remains. The supply of iron came no doubt from the basalt, from which it was leached by water and precipitated as bog ore in the swamps, and later buried beneath lava.

The value of brown hematite, as an ore of iron, consists less in its richness or its purity than in the ease with which it can be exploited and smelted. Nearly all the mines of this mineral are open works, and the ore is soft. It is, however, usually local in distribution, and not generally found in large masses; but since extensive plants for its extraction are not necessary, this is not a vital objection. The future of this ore seems good; for, with the development of the southern states, a large, undeveloped supply will no doubt be drawn upon.

Red Hematite Ores. — This mineral, which in 1880 produced but 1.5 per cent more ore than magnetite, and only 5 per

cent more than brown hematite, in 1891 produced 63.9 per cent of all the iron ore of the country. Out of a total of 14,591,178 tons of iron ore produced in 1891, 9,327,398 tons were red hematite. This remarkable increase is due chiefly to the development of the Lake Superior and Alabama districts, while at the same time, and for the same reason, the output of magnetite decreased.

One of the most remarkable deposits of iron in the world is the Clinton ore bed which occurs in a horizon in the upper Silurian, known as the Clinton, because of its typical occurrence at Clinton, New York. This bed is not always ore-bearing, but in many parts of the outcrop it is a limestone interstratified with shales and limestones. On the other hand, it is frequently iron-bearing. It occurs in New York state, extends southward, following the folds of the Appalachians to Alabama, and is found outcropping in Wisconsin, Ohio, and Kentucky. Throughout its extent it occasionally furnishes iron mines. The ore varies in character, being at times oölitic, when it is called flaxseed ore, or, in other places, replacing fossils, and then being called fossil ore.

There is some question as to the origin of this remarkable ore-bearing stratum. It has been held that the ore was originally precipitated during the formation of the stratum, and the oölitic character of certain parts of the bed seem to prove this. On the other hand, fossils, which were originally calcareous, are now composed of hematite, which shows that, in these cases at least, the ore is a replacement, and hence secondary. At Atalla, Alabama, the Clinton limestone, two hundred and fifty feet from the surface, carries only 7.75 per cent of iron, while at the outcrop it has 57 per cent of

iron, and this seems to prove that here the ore is concentrated by the action of weathering, which has removed some of the calcite. Probably in different places the ore has originated differently. It is not unlikely that, for some reason, during the time of deposit of the Clinton bed, abundant iron was precipitated, producing a ferruginous limestone and, in places, even an oölitic iron bed. Later, percolating water removed some of the iron, and a replacement of fossils and limestone took place, partly from this source and partly from an outside supply of iron. The replacement may have been at first siderite and later hematite. Thus the bed varies in character and richness from place to place, owing to the local concentration, and perhaps, also, as at Atalla, as the result of the concentrating effect of weathering.

The Lake Superior hematites are even more important than the Clinton ore bed, but their occurrence is less simple. There are several districts in Michigan, Wisconsin, and Minnesota. In the Marquette district of Michigan, the ore occurs in strata of quartzites, schists, banded jasper, and limestones of Huronian age (a division of the Archean). There are several types of occurrence, but all are apparently bedded with these strata. As to their origin, Foster and Whitney¹ considered them eruptive, Brooks and Pumpelly² called them altered limonite beds; and the last geologists to study the ore, Irving and Van Hise,³ ascribe the origin of the ore deposits in part to concentration by percolating water, in part to a replacement of limestone. This view

¹ Report on the Geology of the Lake Superior Land District, Part II, 1851, pp. 65-69.

² Geological Survey Michigan, 1869-1873.

³ *The Penokee Iron-bearing Series of Michigan and Wisconsin*, Tenth Annual Report United States Geological Survey, pp. 341-508.

seems the most probable, although it is possible that other explanations may account for some of the deposits. The Menominee district in the same region has a very similar mode of occurrence. Owing to the studies of Irving and Van Hise, the occurrence of the ore in the third district, the Penokee-Gogebic, is well understood. Here the rocks are cherty¹ limestones, slates, quartzites, etc.,

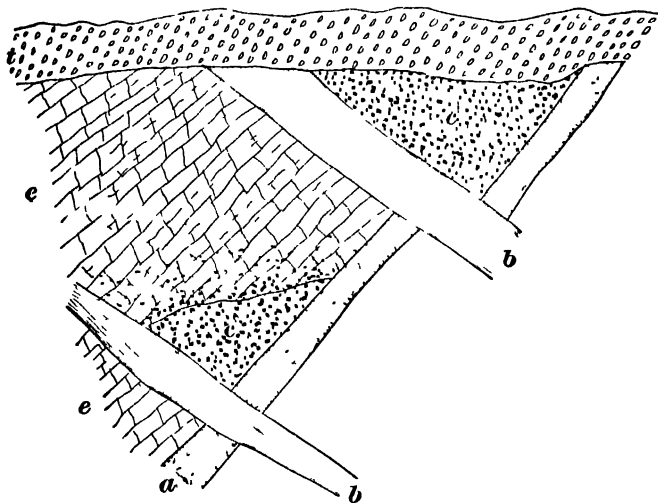


FIG. 15.—Diagram showing mode of occurrence of iron ore in Penokee region. *a*, quartzite stratum, *b*, dikes, *c*, iron ore, replacing ferruginous chert, *e*; *t*, drift. (Modified from Irving and Van Hise.)

dipping at a moderate angle and crossed by trap dikes. It has been shown by these authors that beds of dolomitic limestone, originally stratified with the series, have been replaced by red hematite, and that the ore occurs most commonly in the troughs formed by the intersection of the dikes with the impervious strata beneath the replaced limestones (Fig. 15). The water apparently percolated through

¹ Chert is impure flint.

the limestone, but its progress was retarded by the nearly impermeable quartzites with which the limestone was bedded and by the dikes which crossed the strata. The water being forced to stand here, the limestone was slowly replaced by the iron obtained by solution from the rocks through which the water had percolated.

A part of the same general series of iron ores is found in Minnesota, in the Vermilion Lake and Mesaba Range districts. Here, as in Michigan and Wisconsin, although the ore is sometimes magnetite, it is chiefly hematite. The probable origin of these ores is by replacement, as in Michigan, although Winchell,¹ who has studied the district carefully, believes them to be originally precipitated, together with many of the associated rocks, from an ocean of pre-Cambrian age when the waters were in a transition stage from the heated primary ocean to the cold sea of geologic times. This theory, while very enticing, does not seem as yet to be sufficiently supported by facts for its general acceptance.

One of the most interesting deposits of iron in America is the famous iron mountain of Missouri. Here is a hill of porphyry, rising, dome-shaped, through the much younger Silurian rocks. In the porphyry there are veins of hematite, probably of secondary origin, although some have held that they are an original part of the erupted rock. The ore supply comes, however, from the base of the hill, where it occurs as a conglomerate cemented by limestone and resting upon the porphyry. It is overlain by limestone, and the entire series dips away from the mountain as if deposited upon a sloping surface. No other satisfactory explanation seems

¹ *The Iron Ores of Minnesota*, Bull. No. 6, Minnesota Geological Survey, 1891.

possible than that suggested by Pumpelly,¹ which is, that this hill of porphyry was, in the Silurian period, covered by a soil of disintegration, in which the pebbles of iron, obtained from the veins, remained while the porphyry was decayed to a clay. As the sea which formed the Silurian strata encroached upon this hill or island, the clay was removed and the iron pebbles formed into a conglomerate at the shore line and later covered with other sediments.

The ores of hematite are all *apparently* bedded. This appearance is either due to actual bedding by deposition, or to the subsequent alteration of some previously bedded iron ore of another character (such as limonite), or to the concentration of the ore by some process, usually by replacement. These deposits are frequently lens-shaped, and often attain a considerable thickness in the centre of the lens. Frequently the hematite mines are open works, although where the beds are of a more permanent character, tunnels and shafts are constructed, generally in continuation of previous open-work mining.

Magnetite Ores.—In 1891, 15.88 per cent of the iron ore produced in the country was magnetite, or out of the total of 14,591,178 tons of ore, 2,317,108 tons were of this nature. At present magnetite is the third most important ore of iron, while in 1880 it held second place, and was only a little over one per cent behind the leading ore, hematite. In distribution, the magnetite is found chiefly in the metamorphic rocks of New York, Pennsylvania, New Jersey, and Michigan. Practically all of the New Jersey ore is magnetite, and in both New York and Pennsylvania this is the most important of the iron minerals.

¹ Geological Survey of Missouri for 1872, Part I.

Magnetite is found in nearly all eruptive and metamorphic rocks, as an accessory constituent, in small grains originally formed with the other minerals. It rarely occurs in eruptive rocks in sufficient quantities to pay for mining, although a deposit of titaniferous iron ore, which has been worked at various times, is found in an eruptive rock in Rhode Island. The usual mode of occurrence of magnetite as an ore is typical. It exists as lenses in metamorphic rocks, frequently in the Archean, and often associated with limestone. This mode of occurrence is fully illustrated in New Jersey, in the Archean Highlands, where there is so much magnetite, both as disseminated particles and beds, that the ordinary compass is of no use in the region. These mines have been developed since the last century, and there are thousands of prospect and mine holes, of great and small size, where the dip-compass has indicated the presence of magnetite and encouraged exploration. The beds of iron are associated usually with black hornblendic bands and appear to be bedded with the gneiss, although the apparent bedding of both the gneiss and the iron may be secondary. In the mines the strike is quite uniformly to the northeast and the dip usually southeast, though sometimes northwest, and generally there is, in addition to this, a "pitch" in the direction of the strike, as if the rocks had been folded across the strike. The ore is very irregular, occurring sometimes in pockets, swelling and pinching, and at times being faulted. Some of the veins, as for instance the Hibernia mine of the central Highlands, are remarkably uniform and extensive, but many are so local and irregular that it has been necessary to abandon them. Owing to the distance from coal, the irregularity and uncertainty of the iron deposits, and the

fact that the largest and most uniform have already been worked to a considerable depth, these New Jersey magnetites are rapidly losing in importance; and unless by taking advantage of the magnetic properties of the ore, some process of concentration is perfected, the iron industry of New Jersey must continue to decline. The peculiar occurrence of franklinite on the western border of the Highlands is described under zinc.

At Mineville, Chataugay, and other mines in New York, the occurrence of the magnetite is very similar to that of New Jersey. In the Chateaugay mine, as is often the case in the Archean ores, the magnetite grades, by an increased admixture of gangue, into the barren gneiss of the country. The Mineville deposit which has been worked to a depth of three hundred feet has, since it was opened in 1824, produced up to the close of 1889 over 9,500,000 tons of ore. In this mine the variation in character of the ore, which is even more marked in some other magnetite mines, is well shown. Practically all of the Archean magnetite, unlike the brown or red hematite, is hard and granular, or semi-crystalline. The iron percentage is high and varies in the Mineville ore from 55 to 70 per cent. In the New Bed of this mine a good Bessemer ore is found in which the percentage of phosphorus does not exceed 0.025 per cent; but in one of the old openings the amount of phosphorus varies from 0.5 to 2.5 per cent, owing to the presence of apatite. There is practically no sulphur in this ore, but in some magnetite deposits there is so much sulphur, usually in the form of iron pyrite, that the ore is not mined. Where magnetite is free from both sulphur and phosphorus, on account of the high per cent of iron, it is a valuable ore.

To account for these deposits of Archean magnetite, various theories have been offered. An intrusive origin has been suggested at various times, and certain facts have been stated which seemed to corroborate this view; but, without discussing this theory, it may be stated that there are no facts connected with magnetite deposits which cannot be easily explained by other theories, and that there are numerous objections to this hypothesis which have not been answered. A second theory is that the magnetite beds are, in part at least, altered beds of limonite deposited with the original materials out of which the gneiss has been produced, and metamorphosed to magnetite when the gneisses were formed. While it cannot be denied that this is a possible source of some of these deposits, it may yet be said that it does not seem to be a general explanation. Moreover, the gneisses are so much altered that their original character has never been determined, and without proof this explanation can be called little else than a guess. That some of the Archean magnetites are replacements of limestone beds seems certain, and in some cases is proved; but even this plausible explanation, when applied to the New Jersey magnetite, does not seem to be of general application. A fourth theory, and the one which, taking into consideration all the facts, seems to the writer most probable, is that of segregation; but in advancing it there is no intention of denying absolutely the other explanations. The proofs upon which this belief rests can hardly be stated here. It may be noted, however, that magnetite is present in grains throughout most of these gneisses, and that it is gathered together into strings, bands, and even beds, just as is the hornblende and augite of the gneisses. There seems to be every gradation

from the magnetite grain to the magnetite bed, and it appears to be the result of metamorphism and the gathering together of like minerals from the surrounding rocks during their alteration; that, in other words, it is merely an expression of metamorphism of rocks rich in iron; but whether these rocks were originally limonite-bearing shales or diabase, we cannot in the present state of our knowledge determine.

A very peculiar deposit of magnetite is found in Cornwall, Pennsylvania, occurring in an entirely different position from the above. Here an extremely wide regularly stratified deposit of iron, with a width of more than 400 feet, rests against a trap rock, which has protected it at this point from destruction by weathering, forming a series of hills instead of the valleys which would normally have resulted in this soft deposit. Whether it was originally a pyritiferous shale which has been altered, or a brown hematite metamorphosed to magnetite, seems a question.¹ It is a phenomenal example of cheap mining, the ore being soft so that very little explosive is needed, and the mine being entirely an open-work. Walls of ore eighty feet high are blasted with dynamite. Owing to the great width of the deposit, it can be exploited in a series of retreating terraces at the base of which temporary tracks are laid for its removal. Already, up to 1891, 11,508,990 tons of ore have been won from this deposit, which was first opened in 1740; and there are no signs of exhaustion, but on the contrary boring showing that the ore extends below the water line.

Magnetite is typically a metamorphic mineral. As this ore by rusting alters to the hydrous forms of iron ore so

¹ Professor Lesley states that the deposit is a replaced lime-shale. Summary, Final Report, Vol. I., Pennsylvania Geological Survey, pp. 351-357.

they by metamorphism lose their superfluous constituents and become magnetite. Thus, in whatever original position other ores of iron are found in sedimentary strata, magnetite is also found in the same mode of occurrence in the metamorphic rocks which are altered from these sediments. It has, therefore, the appearance of bedding, and sometimes really is bedded, though more often this appearance is the result of replacement or concentration, by the process of segregation, during metamorphism.

Carbonate of Iron Ores. — This is the least important of the ores of iron, and in 1891 out of the total output of 14,591,178 tons of iron ore, only 189,108 tons, or 1.3 per cent, of the ore of the country was carbonate. In 1880 the carbonate of iron produced 11.57 per cent of the total output, or, during the year, 823,471 tons. At present the only important carbonate-producing state is Ohio, which in 1891 had an output of over 100,000 tons; New York, Kentucky, Pennsylvania, and Maryland being the only other producers of this ore.

The carbonate, siderite, may be considered to be a combination of iron and calcite in which the percentage of iron varies even to the point of complete replacement of the calcium. It occurs as concretions of clay ironstone in beds of calcareous clay; but in this form it is usually too disseminated for mining in this country, although in Europe it is extensively mined. As an ore it is found stratified with slates and sandstones in the Burden mine, near the Hudson, in New York, and it is quite universally found stratified in the other mines, being apparently most frequently a stage in the replacement of limestone beds. The blackband ore of Ohio and Kentucky is a stratified carbonate, coloured black by bituminous matter.

An exception to this general statement is found in a mine at Roxbury, Connecticut, now abandoned, where the ore is found in a fissure vein with quartz, galena, and calcite,—quite an exceptional mode of occurrence.

Foreign Occurrences. — Foreign occurrences of iron illustrate the same general features as those described above, and very little need be said about them. The greatest iron-producing country in the world, next to the United States, is Great Britain, which, up to 1889, was a greater producer than this country. At the time of the Roman conquest, iron mines were opened in the Forest of Dean and elsewhere, and some of these mines are still worked. Throughout the United Kingdom iron ores occur bedded in regular strata, or gathered together along contacts, or in hollows. These ores are chiefly red and brown hematite and the carbonate. They occur in the Carboniferous or mountain limestone, and in the coal measures chiefly; in the latter place being found in the form of clay ironstone concretions, which sometimes coalesce into partial beds. Brown hematites are found also in the Mesozoic strata. Many of the iron ores of the United Kingdom are of very low grade, and are capable of being profitably mined only because of the close association with coal, the coal and iron ore being at times hoisted to the surface through the same shaft. In 1860 the United Kingdom produced 8,155,749 metric tons¹ of iron ore, and the output increased to 1880–1882, when the annual production amounted to over 18,000,000 metric tons. Since then the output has been steadily decreasing, until in 1891 it amounted to only 12,987,159 metric tons.

¹ The metric ton is 2204 lbs.; the long ton, 2240 lbs.; the short ton, 2000 lbs.

Germany, the third in rank as an iron-producer, had an output in 1891 of 10,657,521 metric tons of ore. These ores, which sometimes occur in thick beds, are found chiefly in the Devonian and Jurassic strata in the form of limonite, hematite, and the carbonate. The typical occurrence is bedded, but the ore also occurs in veins often at contacts. Spain, which in 1892 produced 5,465,150 metric tons, is a producer chiefly of brown and red hematite which occurs in Cretaceous rocks. The most important district of this country is Bilbao, which in 1890 produced 4,326,933 metric tons, or nearly the entire output of the country. In order to show the importance of our own iron-producing regions, it may be stated that, in 1890, the total output of Spain, the fourth iron-producing country in the world, was more than 650,000 tons less than the output of the one state of Michigan.

Austria, which has been an iron-producing country since the Roman invasion, illustrates very nearly the same occurrence as the above, and in 1891 produced 1,231,248 metric tons. Belgium also produces hematite, limonite, and clay iron-stone, which is bedded in and below the coal. In 1891 the output was only 202,204 metric tons. Both Norway and Sweden produce considerable iron, chiefly magnetite, the ore from the latter country being remarkable for the very low percentage of phosphorus, that from Dannemora containing only 0.003 per cent, and from other provinces, varying up to 0.05 per cent. This makes a remarkably good Bessemer steel, and the output of iron ore from Sweden in 1891 was 987,405 metric tons. In both Norway and Sweden, as in other parts of Europe where the rocks are metamorphic, the occurrence of the iron ore is

in lenses, apparently of segregated origin, very nearly the same as the ores of New Jersey and the Adirondacks. Both Italy and Portugal have large stores of iron, but owing to the fact that there is no coal at hand, very little is mined in these countries, Italy having an output in 1891 of only 216,486 metric tons. Canada has iron in modes of occurrence similar to that of the United States, although, owing to the great areas of Archean rocks, it is probable that magnetites predominate over the other ores. There are undoubtedly great possibilities in store for the iron industry of Canada, although the general absence of coal over large areas must always interfere with its development. At present, Canada produces very little iron, the output for 1891 being only 62,594 metric tons. The iron ores of Africa, Asia, Australia, and South America are practically undeveloped, not from a lack of supply, but because of the lack of industrial progress. The countries of these continents allow their stores of iron to remain undeveloped, obtaining only a very little for pressing local needs, and depend upon the United States and Europe, Great Britain chiefly, for the greater part of their iron supply. China, which produces not far from 500,000 tons a year, is an exception to this statement.

General Mode of Occurrence.—Iron ores occur disseminated through all rocks, being usually magnetite in the igneous and metamorphic rocks, and hematite, limonite, or carbonate in the sedimentary strata. From one or another of these sources it is taken into solution by water and either precipitated (bog-iron ore), or segregated (some of the New Jersey mines), or caused to replace other rocks (Penokee-Gogebic region), or, under some circumstances, formed into

beds by disintegration and mechanical deposition (Iron Mountain, Missouri). Under all of these circumstances an actual or apparent structure of bedding, either original or secondary, is typically given to iron-ore deposits. Variations from this type of occurrence are distinctly rare. Frequently the beds of ore are very wide, and, unlike most of the ores to be considered, the process of mining is usually by open works instead of in true mines.

Uses of Iron.—The uses of iron are so varied and important that civilization depends upon it more than upon any other mineral product of the earth. Indeed, without a plentiful supply of iron the civilization of the present could hardly have been attained; and, where iron is not present, a high degree of advancement in art and industry is not quickly reached. How much England and the United States owe to their supplies of iron can probably never be told.

The value of iron in the arts depends upon the fact that it is both abundant and cheap, and that, by subjecting it to different processes, it can be made either brittle or malleable, either soft or extremely hard, and either comparatively fragile or extremely tough. Not only can its properties of hardness be varied by heat and tempering, but also, by alloy with such metals as chromium or nickel, a steel of extreme hardness can be produced. The melting-point may also be varied. If iron melted as easily as lead, or was as refractory as platinum, it would be of but little use, yet, for some purposes, it is desirable to have a comparatively low, or, on the other hand, a high, melting-point, and this can be accomplished within a certain range, by different processes. Iron can in one form be cast, thus making it very valuable in

a certain class of work, but in another form, where more durability is desired, it is worked by hammering and welding instead of by casting. There is one great fault in iron, and that is the ease with which it rusts; but by painting or coating with some less easily oxidized metal, as tin or zinc, to exclude the air, this is not so serious an evil as it might at first thought seem to be.

The uses of iron are being extended every year with the advance of civilization and the decrease in cost of iron and iron-working. No single industry has called for a greater supply than the railroads, and now steel vessels are demanding an increasing quantity. These, with bridges and great engineering works, are the largest uses for iron; but in the smaller articles for household, farming, and other similar purposes, great quantities are also used. It is hardly probable that the marvellous increase in demand for iron, which has taken place in the past twenty-five years, will be repeated in the next quarter of a century, although there is little doubt that there will still be a decided increase.

Distribution of Iron Ores. — The ores of iron are widely distributed in this country, yet the areas in which mines are located are extremely limited. East of the Mississippi and a line projected northwards to the Lake of the Woods, the output of iron ore in 1889 amounted to a total of 96.73 per cent of the entire product of all the mines in the country. If this eastern division be divided by an east and west line extending along the Ohio and Potomac, the product of the northern portion, according to the census of 1890, is 76.82 per cent of the total output of the United States. While this rather remarkable distribution is in part due to the geological conditions, it is chiefly the result of the fact that the

industrial progress of this section has been greatest. Undoubtedly the two conditions have been interacting, the increase in industrial demands calling for more iron, while, on the other hand, the presence of the supply has without question aided in the progress. Ten years ago this division was much more marked, and already the centres of the iron supply are moving southward and westward; and, as these sections develop industrially, their stores of iron will be more and more called into use.

Carrying the consideration of iron-ore distribution to a still smaller division of areas, one is impressed by the fact that workable deposits are extremely local. The four iron-bearing ranges of the Lake Superior region are all included in a semi-circle, with a radius of 135 miles and a centre in Lake Superior, the greater part of the mines being near the periphery. In 1889 this district produced 7,519,614 tons¹ of ore. A parallelogram sixty miles in length and twenty miles in width would include all the mines of the Lake Champlain district of northern New York, from which, in 1889, 779,850 tons of ore were won. A circle of fifty miles' radius, embracing portions of Alabama and western Georgia, included mines which, in 1889, produced 1,545,066 tons of ore, and a single locality, Cornwall, Pennsylvania, contributed 769,020 tons. From these districts alone, 10,613,550 tons, or 73.11 per cent of the entire output of iron ore of the United States, were obtained in 1889.²

During the year 1891 the four states, Michigan, Alabama, Pennsylvania, and New York, each produced over 1,000,000

¹ Long tons are used in the statistics for the United States.

² The facts in this paragraph were obtained from the volume on *Mineral Industries* of the Eleventh Census Reports, p. 9.

tons of ore; and Michigan had an output of over 6,000,000 tons; Minnesota, Virginia, Wisconsin, Tennessee, and New Jersey each produced over 500,000 tons, and less than 1,000,000; Georgia, Colorado, Missouri, and Ohio each produced between 100,000 and 500,000 tons. Thus thirteen states only may be considered important iron-producing states, and of these only one is in the Cordilleran region.

Reviewing hurriedly the output of each of these states, it is found that Michigan has, in 1891, decreased its output over 1,000,000 tons since 1890, but still produces 41.99 per cent of the iron ore of the country. Of this ore, 88.87 per cent was red hematite, 7.47 per cent brown hematite, and 3.66 per cent magnetite. More than one-half of the red hematite of the country comes from Michigan. The several districts which produce this ore are situated on the peninsula between Lakes Superior and Michigan; and more than three-fourths of it comes from nineteen mines, five of which, in 1891, produced over 300,000 tons each, four between 200,000 and 300,000 tons, and ten between 100,000 and 200,000 tons.

The development of the iron industry in the various districts of the Lake Superior region since 1883 is shown in the table on page 140.

Alabama, the second state as an iron-producer, continues to increase its output, and in 1891 the production was 1,986,830 tons, or 13.62 per cent of the iron ore of the country. The ore is chiefly red hematite, although about one-fourth was brown hematite, and in both the red and brown varieties it is the second most important producing state, its output of red hematite being 16.35 per cent of all produced in the country, and of brown hematite 16.76 per cent. There are six mines in Alabama which produced over

PRODUCTION OF LAKE SUPERIOR IRON-ORE MINES FOR THE LAST TEN YEARS.¹

LONG TONS OF 2240 LBS.

RANGE.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	TOTAL.
Gogebic . . .	..	1,022	119,860	747,589	1,303,267	1,424,699	2,016,391	2,847,786	1,895,599	2,973,993	13,260,206
Marquette . .	1,305,425	1,548,034	1,480,422	1,627,380	1,851,414	1,918,750	2,634,816	2,993,664	2,512,242	2,606,856	20,540,003
Menominee . .	1,047,415	895,634	690,435	880,006	1,193,343	1,101,101	1,796,755	2,282,237	1,824,619	2,261,499	14,263,044
Mesaba . . .	..	..	..	..	..	..	..	..	..	4,245	4,245
Vermilion . .	..	62,124	225,484	304,396	394,252	511,953	844,682	880,014	894,618	1,167,650	5,285,173
Total . . .	2,352,840	2,506,814	2,516,201	3,559,371	4,472,276	5,046,503	7,292,644	9,003,701	7,057,078	9,074,243	53,151,671

¹ *The Mineral Industry, 1892, Rothwell.*

The largest single mine in this district is the Norrie mine of the Gogebic Range, Michigan, which produces about 1,000,000 long tons of ore per year.

100,000 tons of iron ore in 1891, and from one mine, the Tannehill mine in Jefferson County, in an area of two acres, 115,563 tons of brown hematite were produced. In 1880 Alabama produced only about 171,000 long tons of ore; in 1885 the output reached 500,000 tons; in 1888 about 1,000,000 tons were obtained; and now (1891) the state produces nearly 2,000,000 tons, the greater part of which comes from the vicinity of Birmingham.

All four kinds of ore were produced in 1891 by Pennsylvania, making a total of 1,272,928 tons, or 8.72 per cent of the output of the country. Of this, 727,299 tons were magnetite, giving to Pennsylvania the second rank as a producer of this ore, or 31.39 per cent of all produced in the country; of brown hematite the output amounted to 363,894 tons, giving to the state fourth place as a producer of this ore; of red hematite only 162,683 tons were produced; and of the carbonate 19,052 tons. The output of magnetite and brown hematite has decreased since 1890, while that of red hematite and carbonate has increased. In 1891 the only mine in Pennsylvania which produced more than 100,000 tons was that of Cornwall, from which the magnetite supply is obtained. Many mines in Pennsylvania have been closed either because of leanness, excess of phosphorus, or expense of exploitation, which prevents competition with the cheaply mined and transported ores of other sections.

New York is the only state, other than Pennsylvania, which produced all four ores of iron, and here, also, the greater part of the ore is magnetite. In 1891, 782,729 tons of magnetite were produced, out of a total of 1,017,216 tons of iron ore, which gives to New York first rank as a producer of this class of ore. The brown hematites come chiefly from

the eastern part of the state in a region known as the Salisbury district of New York, Massachusetts, and Connecticut; the red hematites are found in the central and northern portions; the carbonates occur at the Burden mines on the Hudson; and the magnetites in the Lake Champlain, western Adirondack and southeastern Archean districts, the first being the most important district.

Minnesota advanced from sixth place in 1890 to fifth place in 1891, producing then 945,105 long tons of red hematite, in which it ranks third as a producer. Although all of the ore obtained during 1891 came from three companies in the Vermilion Range, much prospecting was done in the newly discovered Mesaba Range, and it is reported that companies with a total capitalization of \$75,000,000 were formed to open up the remarkable deposits of limonite, hematite, and magnetite, which occur there. The future of this district seems very promising, for the ore is both of good quality and quantity, and already in 1892 the region began to produce ore. Nearly all of the ore of Virginia is brown hematite, of which there were 653,342 long tons in 1891 of the total output of 658,916 tons of iron ore for the state. Virginia takes first rank as a producer of this ore, supplying 23.69 per cent of the country's total, and the output is increasing. While these ores, which come chiefly from the Shenandoah valley, have not a high per cent of iron, they are easily smelted and make good iron, but they are not suited for Bessemer steel.

Wisconsin has decreased its output of iron by nearly 400,000 tons since 1890, and in 1891 its output was only 589,481 tons, causing it to drop from fifth to seventh place. Nearly all of the ore is red hematite, coming from the end of

the Menominee and Gogebic ranges, which extend over the line of Michigan into this state. There are extensive deposits of brown hematite near the Mississippi, but as yet these have been only slightly developed. Tennessee produced 543,923 tons of iron ore in 1891, an increase of 16.80 per cent over the preceding year. Of this, 396,883 tons were of red hematite, which has increased since 1890, and the balance brown hematite, in which the state has decreased its output. The red hematites come from the eastern portion of the state in the valley of the Tennessee River. Over 98 per cent of the iron ore of New Jersey is magnetite from the mines of the Archean Highlands, some of which, as the Dickerson, have been operated since early in the last century (the Dickerson since 1713). This mine, together with others in New Jersey, has been closed since 1891. Although New Jersey has steadily decreased its output for a number of years, there was an increase of 6.01 per cent in 1891, when the output was 525,612 tons; but the years 1892 and 1893 will undoubtedly show a marked decrease.

Georgia, Colorado, Missouri, and Ohio, each decreased their output of iron ore from 1890 to 1891. The ore of Georgia is chiefly (82.04 per cent) brown hematite, with some red hematite. Colorado also produces chiefly brown hematite (89.46 per cent in 1891), with some red hematite and magnetite, the chief supply from this state being used as a flux in smelting. Only about 7 per cent of the ore of Missouri is brown hematite, and the balance is red hematite. Missouri continues to decline as an iron-producer, though not because of the exhaustion of its mines. The most important mine of the state is the Iron Mountain, which since 1847 has contributed 3,349,086 tons of ore. All of the iron ore output

of Ohio is the carbonate, and the iron industry of this state continues to decline owing to the poverty of the ores and the competition of the Lake Superior mines.

During the year 1891 the supply of red hematite came chiefly from the four following states named in the order of importance, each of which produced over 500,000 tons: Michigan, Alabama, Minnesota, Wisconsin; of brown hematite, from the five following states, each of which produced over 200,000 tons: Virginia, Alabama, Michigan, Pennsylvania, Georgia; of magnetite, from the four following states, in each of which the output was over 200,000 tons: New York, Pennsylvania, New Jersey, Michigan; of the carbonate only one state, Ohio, produced more than 100,000 tons, and the other carbonate-producers were unimportant.

Production of Iron.—In the United States the development of the iron industry is shown in the following table for the six leading states:—

PRODUCTION OF IRON ORE IN THE UNITED STATES.

LONG TONS (2240 LBS.).

	1850.	1860.	1870.	1880.	1891.
Michigan	2,700	114,410	859,507	1,640,814	6,127,001
Alabama	1,838	3,720	11,350	171,139	1,986,830
Pennsylvania	877,283	1,351,000	2,337,286	1,951,495	1,272,928
New York	46,385	151,378	446,945	1,126,900	1,017,216
Minnesota . . . . .	..	..	..	..	945,105
Virginia and West } Virginia }	67,319	28,109	84,108	217,448	665,116 ¹

The following table shows the change in rank of the iron-producing states since 1850:—

¹ In 1891 West Virginia produced only 6500 tons.

1850.	1860.	1870.	1880.	1891.
Pennsylvania	Pennsylvania	Pennsylvania	Pennsylvania	Michigan
Ohio	Ohio	Michigan	Michigan	Alabama
Kentucky	New York	Ohio	New York	Pennsylvania
New Jersey	Michigan	New York	New Jersey	New York
New York	New Jersey	New Jersey	Ohio	Minnesota

Thus, Michigan, Alabama, and Minnesota have shown a remarkable increase since 1870, Pennsylvania a marked decrease, and New Jersey, Ohio, and Kentucky have also decreased. The transfer of the iron industry from the northern Appalachians to the Lake Superior and Alabama regions is very striking. In 1889 Michigan produced 40.34 per cent of the iron ore, Alabama 10.82 per cent, Pennsylvania 10.75 per cent (in 1870 Pennsylvania produced 44 per cent), and New York 8.59 per cent, the four states combined producing 70.5 per cent of the total output of the country, four-sevenths of which came from Michigan.

The production of iron ore in the United States in the decades since 1850 is as follows: —

PRODUCTION OF IRON IN THE UNITED STATES SINCE 1850.

1850	1,560,442 long tons.
1860	2,396,485 " "
1870	5,250,402 " "
1880	7,489,464 " "
1890	16,276,584 " "
1891	14,591,178 " "

While the United States exports considerable iron ore, it imported in 1892 only about 800,000 tons, and has never imported in any one year much over 1,000,000 tons. The

imported ore comes chiefly from Spain, Algeria, and Cuba, and is used almost entirely for Bessemer steel.

PRODUCTION OF IRON ORE IN THE WORLD.

	1889.	1890.	1891.
United States . . .	14,518,041	16,276,584	14,591,178 long tons ¹
Great Britain . . .	14,546,105	13,780,767	12,987,159 metric tons
Germany and Luxem- burg }	11,002,187	11,400,625	10,057,521 “ “
Spain	5,067,144	5,788,000	4,822,080 ² “ “

The total production of iron ore for the world in 1890 was approximately 55,000,000 long tons. In 1890 the United States took first rank as an iron-producing country, supplying 28.9 per cent of all the iron ore of the world. From this iron ore, 9,353,020 metric tons of pig iron were produced and 4,346,932 tons of steel, no allowance being made for the imported ores. The total value of the iron ore produced in the United States in 1890 was \$33,364,958.

¹ Long tons, 2240 lbs. ; metric tons, 2204 lbs.

² The output of Spain has increased in 1892 to 5,405,150.

CHAPTER VII.

GOLD AND PLATINUM.

Gold.

General Statement. — The gold product of the world comes chiefly from native gold, which, in most cases, exists either in quartz veins or in gravels resulting from the decomposition of gold-bearing rocks, and the separation and accumulation of the *débris* by running water. Aside from this source there is, however, a large supply furnished as a by-product in silver and copper mining, and also a smaller supply from mines of other metals. So far as we know, the greater part of the gold from this source is mixed mechanically and without chemical combination, unless an alloy be considered a chemical rather than a mechanical mixture. All of the gold which is called native contains silver in alloy (usually from 8–10 per cent), as well as smaller quantities of other metals, and much of the silver ore is gold-bearing. The two industries of gold and silver mining are therefore intimately related, and are often considered together; but it seems well here to discuss the two metals separately.

Appalachian Gold Fields. — Prior to the year 1848, when the gold of California became an important element of our mineral wealth, the gold of the country came chiefly from the southern states, which produced over \$1,000,000 worth a year, but which now, in 1892, have a total output of only \$306,015.96. This marked decrease was due first to the

exodus of the miners to the new fields, and later to the interference of the Civil War; but the gold industry thus paralyzed, again became important in 1870, and since then the output has been slowly increasing, excepting during the past few years, when there has been a slight decline. The gold in this section comes chiefly from South Carolina, Georgia, and North Carolina, where it occurs in the belt of talcose schists which extend east of the Appalachians proper from these southern states into Canada, being auriferous for the greater part of the distance, although usually with such a small percentage of gold that it cannot be profitably extracted. If there were ever placer deposits in the northern states along this belt, these were swept away by the glacial invasion; but in the southern states placer deposits were found and worked, at first, then mines were opened in the schists, and now, owing to the introduction of the advanced methods of reduction of the more refractory ores, these mines are below the water line. Of the seventy-one mines in operation in these states in 1889, thirty-one were in North Carolina, twenty-two in Georgia, and seven in South Carolina. Three of these mines produced over \$20,000 worth of gold, and ten between \$10,000 and \$20,000 worth. It will be seen, therefore, that these mines are not very extensive nor valuable, although from the seven gold-producing states of this section, there has been produced, between the years 1799 and 1891, about \$44,000,000.

California Quartz Mines. — With the discovery of gold in California, there was a transfer, not only of the industry, but also of the miners themselves, from the extreme east to the extreme west of the country. Not only was there an exodus of miners, but hordes of totally inexperienced men travelled

to the new gold placers, until, at the close of 1850, it is estimated that there were not less than 50,000 men in the gold fields, many of whom earned from \$1000 to \$5000 a year, while some became wealthy almost in a day. The history of the excitement of these times, of the development of crime and its suppression, the suddenly made and equally suddenly lost fortunes, and the hopes which were never fulfilled, forms a most interesting chapter in the history of the nation, a parallel of which has probably never before existed. The west developed with wonderful rapidity from an uninviting almost desert region, occupied by savages, to its present state of civilization, although even now the effects of these conditions are still manifest in many places: and, indeed, some of the very conditions themselves are still present in some parts of the west. It may be said that the west was literally created by the discovery of gold, followed by that of silver and other metals, and the necessary development brought about by these discoveries. Nor are the effects confined to the west; for the country as a whole has been greatly benefited by the production of these vast stores of mineral wealth.

At first the rush was all to the newly discovered gold fields of California, but soon the prospectors found that there were almost equally rich fields in the intervening territories, and the base of their operations spread rapidly over the whole area of the Cordilleras. Superficial stream gravels first attracted attention, then the older gravels were discovered, and soon the source of the gold itself, in the rocks, was explored, and now the chief supply of the gold comes from these permanent and original sources.

In California the gold occurs in the Jura-Trias slates of

Mesozoic age, which are folded to form the Sierras and extend as highly tilted strata in a nearly north and south direction parallel to the axis of these mountains. These slates are traversed by quartz veins extending in general parallelism with the strike and dip of the rocks, but not strictly so. The largest of these, the so-called "Mother Lode," is a great quartz vein, outcropping boldly as a ledge above the surface, like a great white wall, and extending parallel to the axis of the Sierras for a distance of seventy or eighty miles from Mariposa to Amado. It is not, strictly speaking, a continuous vein, nor is it everywhere productive, but it varies in width from six to sixty feet, and consists of a series of veins, pinching-out or ending in offshoots, with frequent barren spaces. Other smaller veins are found in general parallelism with this. At the surface the quartz is semi-transparent or translucent and usually iron-stained by the rust of the decayed iron pyrite which it originally contained. Below the water line the quartz is found to contain iron pyrite, copper pyrite, zinc blende, galena, and other minerals; and in all of these sulphides, as well as in the quartz itself, gold is found, sometimes in flakes and grains, but often in microscopic quantities. By the decay of the sulphides, cavities, usually iron-stained, are formed, and in these, as also in the quartz itself, the gold is found in the surface ledges. The typical surface gold-bearing veinstone in this region is therefore a cellular, iron-stained, translucent quartz.

This was the first ore discovered by the gravel-washers, who, finding that the placer deposits occurred locally, naturally looked about for the source of the gold. The discovery of these ores marks the second stage in the development of the gold industry of the west. When the auriferous quartz

ledges were mined and crushed, and extensive hydraulic works established for washing gravels on a large scale, the individual prospector began to be replaced by mining companies, although, even to this day, the prospector may still be seen washing the stream gravels in California and elsewhere in the Cordilleras. With the establishment of companies, extensive plants were constructed for crushing the quartz and removing the free gold by concentration and amalgamation; but when the water line was passed and the undecomposed sulphides encountered, new methods needed to be introduced, and the third or present state of the gold-mining industry of California was reached.¹ Low-grade ores of this nature carry from \$3.50 to \$8.00 of gold per ton, and high-grade ores yield from \$15.00 to \$30.00, while the average is probably from \$10.00 to \$12.00 a ton. By the new and more economical processes, ore which a few years ago was considered worthless, can now be worked, since nearly everything is saved, whereas formerly much gold was wasted. It was for this reason that miners believed that the ore decreased in quantity as the lode extended into the earth.

The description of this mining region applies almost equally well to the majority of the mines of the country, and, indeed, of the world, where the ore is primarily gold. Still, at times, the gold is found in other occurrences, as, for instance, in the Spanish mine at California, where it occurs in a bed of steeply dipping soft slates, which are traversed in every direction by small quartz veins. Here

¹ A very complete description of these processes of gold reduction, the chlorination and cyanide processes, will be found in *The Mineral Industry*, etc., 1892, Rothwell, pp. 233-270. A very good description of the general process of gold-mining and reduction may be found in the Eleventh Census volume on *Mineral Industries*, pp. 103-108.

the metal exists not only in the quartz, but also in the clay-partings between the veins and the country rock, and even, in small quantities, in the slate itself. In El Dorado County there is another mine, the Dalmatia, which is worked at low cost owing to the softness of the rock, in which the occurrence of the gold is slightly irregular. A band of chloritic schist, having a width of about 125 feet and bounded by clay slate, is crossed by gold-bearing quartz veins; and the entire rock is so badly decayed and so soft that, owing to its width, the deposit is quarried in an open pit. Both the quartz and the schist are obtained and crushed, and the mine pays although the rock carries only from \$1.50 to \$2.00 worth of gold to the ton.

What the origin of these gold deposits is cannot be definitely stated. For many years the "Mother Lode" has been used as a typical illustration of the segregation type of vein; but recently¹ it has been proved that the vein crosses the slates at an angle to the structure, and is therefore unlike a typical segregation vein. Yet it has never been shown that this lode is a true fissure vein, and it is surely not an eruptive deposit. In spite of the recent observations it still seems that these quartz veins must be of segregation origin. The rocks in which they occur were deposited in Mesozoic times and have been metamorphosed to their present condition by the folding of the Sierras, of which they form a part. It seems not unlikely that the quartz veins are one of the results of this metamorphism; and the fact that the gold is found also in the enclosing slates and schists seems to indicate that it was originally a part of the sediment out of

¹ Fairbanks, *Geology of the Mother Lode Gold Belt*, Am. Geologist, 1891, Vol. VII., pp. 209-222.

which these rocks were built, having been during their metamorphism gathered together in flakes and tiny bits both in the rocks and in the quartz veins which have been formed. Exactly the same process is seen in many slates where, by metamorphism, iron pyrite is gathered into crystals and accumulations of crystals, both in the massive slates and along the cleavage and joint planes, as well as in veins of quartz and calcite which traverse the slates. Although it cannot be said that we definitely understand the process by which the gold has been accumulated, it may be stated that the process of segregation seems best to account for all the facts observed.

California Auriferous Gravels.—By the disintegration of the slates and quartz veins through a long period of time, the more easily destructible minerals, together with the light but chemically durable quartz, have been carried off, while the heavy, indestructible gold has in part remained behind and accumulated in the river gravels. These placer deposits are of two kinds, — those which have accumulated in recent, and those which were formed in old and now extinct river beds. During the Tertiary period the Sierras, which had then attained much of their growth, were subjected to long-continued denudation, the rocks were gradually worn away, and an extensive series of well-developed valleys were formed, extending from the mountains out upon the plains at their base. It thus happened that by a process of natural hydraulic concentration gold was accumulated in these valleys, particularly on the more level plains at the base of the mountains where the river currents were slackened. But for a subsequent change, however, these accumulations might have been gradually swept seawards and have been

lost. During the close of the Tertiary period the remarkable outburst of volcanic activity, which extended over the entire Cordilleras, and has only in recent times ceased, sent floods of lava out upon the surface and these naturally sought the valleys as the easiest direction of flow. Thus many of the valleys were flooded with lava, which forced the streams to carve new channels, and which, when it cooled, formed a durable protection to the soft and easily removed gravels. As the result of subsequent erosion the river valleys were chiefly formed at the side of the lava flows, and because of the

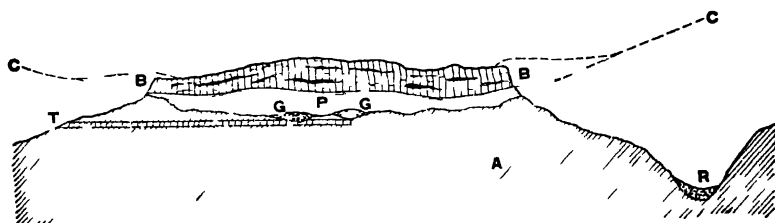


FIG. 16. Cross section of Table Mountain, California showing auriferous gravels (G) beneath basalt (B) P, pipe clay T tunnel C continuation of ancient valley, A, slates R, recent river containing gold bearing gravels (After Whitney.)

hard lava-capping, the old stream beds became lava-capped hills consisting in part of gold-bearing gravels¹ (Fig. 16).

These buried ancient river gravels are now mined, partly by hydraulic means, partly by tunnelling; and the gold is found, just as in the modern valleys, in spots, or in "pay streaks," in what are called "pay gravels" in distinction from the unremunerative gravels which predominate and contain either very little or no gold. The gravels are sometimes from 150 to 250 feet thick, and in the famous Table Mountain of Tuolumne County the basalt covering is 150

¹ These were once supposed to be marine gravels, but are now known to be river gravels because of their structure, character, and fossil contents.

feet thick. Five conditions have therefore conspired to bring these accumulations of gold-bearing gravels into their present position: (1) the chemical decomposition of the iron pyrite and the mechanical destruction of the auriferous quartz; (2) heavy valley grades in the mountains and a decreasing slope on the plains; (3) large quantities of water; (4) a long-continued time for action; (5) the protection from subsequent destruction furnished by the basaltic lava flows.

Partly by the working over of these old river gravels in the new streams, and partly by a new supply furnished them by the subsequent disintegration of the gold-bearing rocks, the placer deposits which were first discovered, and which exist in all of the states and territories of the Cordilleras, were formed. The amount of gravel which has been washed by hand and by hydraulic processes can be realized only by actually visiting the region. Millions of dollars' worth of gold have been taken from single washings, and cities (such as Helena, Montana) have been built upon the sites from which the metal was won. Associated with the gold in the gravels, platinum and the precious stones, diamond, topaz, and sapphire, have been occasionally found, although until recently no systematic operations for their recovery have been instituted.

At first the gravels were washed by hand, but it was not long before such a simple process was found to be too slow a road to wealth, and the prospectors invented the process of hydraulic mining (Frontispiece)¹ in imitation of

¹ Descriptions of the gold fields, particularly of the gold gravels, and the mode of extracting the metal from them, will be found in Whitney's *Auriferous Gravels, Metallic Wealth of the United States, The United States*, pp. 309-339; and also in the Eleventh Census volume on *Mineral Industries*, pp. 106-108.

the more extensive but very similar method of concentration which nature had long made use of in accumulating the gold gravels. A stream of water is led to the gravel deposit and directed against the bank, washing the *débris* into sluices, where the gold collects behind riffles, and is held in amalgamation by mercury, while the lighter minerals and fragments of rock pass onward. In order to obtain sufficient water and a sufficient force, pipes are constructed, often for a distance of many miles and at great expense, bridging valleys, passing through tunnels, and even crossing divides. Where the hydraulic mines have been abandoned, these expensive works still remain, in many places the only sign of the former gold-mining operations, if we except the stream bed littered with gravel, and the partly destroyed gravel banks. Sometimes towns, which grew up almost in a day, are now found abandoned near these deposits.

An ingenious contrivance known as the hydraulic elevator is sometimes used for washing gravels situated in low places. By means of this the gravel is forced up hill by a powerful current of water, and then the gold is obtained.

Hydraulic mining in California very quickly found an enemy in the farmer who dwelt upon the stream below the sluices; for, by the immense amount of gravel which was washed into the streams, their farming lands and farming operations were seriously interfered with, and it soon became a question which should survive in these places, the farmer or the miner. The question was settled in 1884 in favour of the farmer by an injunction, issued by the United States Circuit Court, which caused many of the hydraulic mines to suspend operations; and more recently

this has been extended by state legislation adverse to the hydraulic mining industry. Owing to this set-back, hydraulic mining fell to a comparatively unimportant place in the gold-producing industry of California, while at the same time quartz mining increased. Within a year or two, the Circuit Court having modified its injunction, a number of the abandoned hydraulic mines have commenced operations again, and the future of this industry seems good. It is now proposed to construct dams below the sluices, under the direction of government engineers, and thus, by forming catchment basins, to save the farmers from the flood of sediment and its destructive effects.

Origin of Nuggets.—In placer deposits the gold is found chiefly in small flakes and grains, but sometimes large pieces called “nuggets” are discovered. It has been suggested that they are formed by some chemical change during or after the accumulation of the gravels, but for various reasons this seems improbable. The most probable origin of nuggets is by actual derivation from the quartz veins, although perhaps their size has been increased by the welding of one fragment to another as they pass down stream in company with small pebbles, and even large boulders. A gold mass weighing 500 ounces has been found in one of the quartz veins in Victoria; but this is small compared with the two large nuggets from the same region, one of which, the “Welcome Stranger,” weighed 2280 ounces, and the other, the “Welcome Nugget,” which contained 2166 ounces of gold and ten pounds of quartz and other gangue minerals. That they are derived from the veins seems shown by the fact that they usually contain some quartz, and that they are generally rounded as if rolled

about in the stream. The discrepancy in size suggests the welding of fragments of gold, although it does not prove it, for large nuggets are rare, and the gold gravels represent in a small space the accumulations from the destruction of large areas of quartz, while the actual mining operations in the veins are of comparatively limited extent. It is possible therefore that fragments as large as the largest nuggets may yet be found in the quartz veins.

Other Western Gold Fields. — The other states and territories of the Cordilleras have gold-bearing gravels and auriferous quartz in very nearly the same mode of occurrence as in California, and it would be mere tedious repetition to describe other mines of this region, although there are some points which need to be mentioned. Colorado is second in importance as a gold-producing state and ranks first as a producer of the precious metals. Both placer and quartz mines are worked there, some of the latter being free-milling and some mixed with sulphides, just as in California. A very considerable percentage of the Colorado gold comes from the silver mines, from which it is produced as a by-product. South Dakota, chiefly the Black Hills district, also produces gold from the same sources, and here also there is an interesting occurrence of gold in Cambrian sandstone derived from the disintegration of the Archean rocks in early Palæozoic times. Montana, Nevada, Idaho, Oregon, Arizona, New Mexico, and the other states and territories of the Cordilleras illustrate the same modes of occurrence, but here the output is less than from the above-mentioned states. In Montana, in addition to the placer and quartz deposits, there is much gold produced as a by-product from the silver and copper mines.

Nevada continues to fall in importance as a gold as well as a silver producing state. The greater number of the mines of Nevada, aside from those on the Comstock Lode, are silver mines, and hence the chief gold supply from this state comes from the Comstock. This mine, which is described in the chapter on silver, in 1891 had an output of only \$1,200,000 of gold, although at one time the output exceeded \$14,000,000 in a single year (1877), and between the years 1859 and 1891, inclusive, there has been produced from this lode \$140,771,979 of gold. Aside from the occurrences of gold described above, in all the states and territories this metal is found in eruptive rocks, porphyries, granites, diorites, etc., sometimes disseminated and sometimes in quartz veins which traverse them, chiefly in the latter. Gold is also found as the telluride, but the typical mode of occurrence in the rocks is in the native state associated with sulphides in quartz veins traversing metamorphic and igneous rocks.

Such wonderful "bonanza" mines as the Comstock are, of course, liable to be found at almost any time, but at present there are none in operation. In all of the states and territories new mines are being opened, and many of these, together with the older ones, are being operated upon an economical and scientific basis. On the whole, although the output of gold is not rapidly increasing, it has in the past decade more than held its own, and the future seems very promising. The bright outlook for the future of gold is increased by the recent disastrous drop in the price of silver¹ and the consequent suspension of operations in some of the mines, which will serve to direct the energies and capital of

¹ The fall in price in the early summer of 1893.

many from silver to gold production. The industry of gold mining may now be said to be more than a mere speculation, or a game of chance, for it has become a business, as safe, where properly managed, as any other mining industry.

Alaskan Gold Mines. — One of the most striking developments of gold mining in this country, in the past ten years, is the opening of the Alaskan fields. For a number of years prospectors have panned gold from the rather limited gravels of this region, but it has been within only a very few years that actual mining operations have been begun. Now mines are opened in many parts of the territory, but chiefly along the coast line. The prospectors are now at work in the interior, in the valley of the Yukon, and they report valuable deposits of gold in this region; but mining there is difficult, owing to the shortness of the season, the cold and disagreeable weather, and above all the difficulty of obtaining a food supply. At present the most important district in Alaska is Douglas island, where the Treadwell mine is situated. Here placer deposits were discovered in 1881, and upon their removal a low-grade gold-bearing quartz was found beneath. The ore and gangue consist of quartz and calcite carrying free gold and gold-bearing iron pyrite; and everything between the walls, which are 550 feet apart, goes to the stamp mills, the ore being mined, or rather quarried, in large open pits. It is worthy of note that 240 stamps are constantly at work whenever there is sufficient water, and steps are being taken to improve the water supply, so that they may work steadily. Other districts are being developed, and there is every reason to expect that gold mining will serve as a means of opening to settlement a large part of this domain, as it

did our great western country, with such wonderful rapidity, in the middle of the century.

The following table shows the remarkable development of the industry in Alaska, but it does not represent the actual output of gold, since many individual placer-miners carry their gold to San Francisco.

PRODUCTION OF GOLD IN ALASKA.

1880	\$6,000	1884	\$200,000	1888	\$850,000
1881	15,000	1885	300,000	1889	904,000
1882	150,000	1886	446,000	1890	762,000
1883	300,000	1887	675,000	1891	900,000

Foreign Gold Regions. — *Australasia.* Second in importance to the United States is the Australian gold region, the discovery of which followed closely upon the opening of the California fields. In 1851 gold was first discovered in Victoria, and until 1856, when the richer alluvial deposits began to be exhausted, the output rapidly increased; but since then there has been a decrease in production, although the quartz mines have increased in number and production. During the years 1855 to 1857 the output was in each year over £11,000,000 sterling, but in 1891 it was only about £2,300,000 sterling. As yet the methods of ore reduction are not as advanced as those of the United States, so that the full capacity of the mines is not fairly tested, and because of insufficient slope the process of hydraulic mining is not extensively used. There are several districts in Victoria, of which two, Ballarat and Sandhurst, are the most important. The mode of occurrence varies slightly, but

bears a marked resemblance to that of California, the gold being found in auriferous quartz, old river gravels, and new river gravels. Usually the quartz veins traverse diorite, granite, and sandstone, but the rocks are of Palæozoic instead of Mesozoic age, as in California. It is supposed that the quartz veins are of segregated origin, and that the supply of gold comes chiefly directly from the eruptive rocks. Both the recent and ancient (Tertiary) river gravels very closely resemble those in California, the latter even to the fact that they are covered by lava flows. Here, however, owing to the difference in erosion, the gravels are exploited by means of shafts, instead of tunnels, and the mines are drained by pumps so that gravel mining is much more difficult here than in California (Fig. 17). From all the mines in Victoria, between the years 1851 and 1891 inclusive, £229,787,892 sterling of gold have been produced.

New South Wales has gold occurrences of almost exactly the same character. Here gold is also found in the consolidated conglomerates of the Carboniferous period, showing that at this time conditions of accumulation existed which were very similar to those prevailing in the Tertiary period. From this country, in the forty-one years succeeding 1851, the gold product has been worth £38,633,489 sterling. In New Zealand the same occurrences are noticed, and, in addition, some gold is obtained from the seashore sands. The river gravels are sometimes consolidated, and it is then necessary to crush them as in the case of the quartz and the Carboniferous conglomerate. Since 1857 to the close of 1891 New Zealand has supplied gold to the amount of £47,433,077 sterling. Gold is found in Queensland in quartz veins traversing Devonian slates as well as in gravels,

and this country has produced £28,052,199 sterling of gold. Tasmania has gold in the same modes of occurrence, and although the output is comparatively small, the future seems good. South and Western Australia are also gold-producing regions, but they are of less importance than the other sections. Although at present Australasia is second in importance to the United States as a producer of gold, there have been years since 1851 when the United States was of second rank. Yet the total output of gold from the entire Australasian region which, between 1851 and 1891 inclusive,

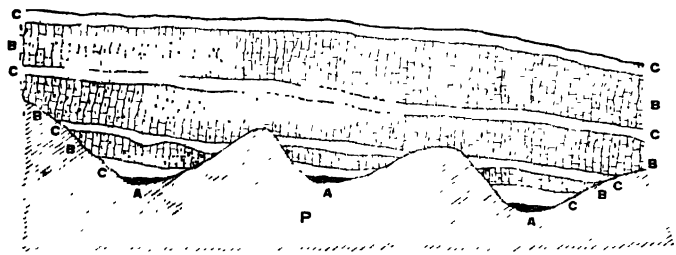


FIG. 17.—Section showing the position of the gold-bearing gravels in New South Wales. *A*, gold-bearing gravels; *B*, basalt; *C*, clay strata; *P*, Palaeozoic strata.

amounts to \$1,690,137,137 is somewhat less than the output of the United States for the same period of time.

Russia and Siberia.— Before the discovery of gold in California, in 1848, the Russian empire held first place as a gold-producing region ; but it soon fell to second rank, and after the discovery of gold in Australia, to the third place, which it now holds. The production of gold in the Urals began in 1745, from the placer deposits in 1774, and since 1822 the output from the placers has exceeded that from the quartz mines. In eastern Siberia gold was discovered in 1704, and placers in 1829. Since then, this, the most important gold

district of the Russian empire, has been chiefly a region of placer mining. There is also an important district in the Altai Mountains in western Siberia, and gold is produced also in Finland and in the Caucasus Mountains. Gradually the mining-centre has been transferred from west to east, the source being chiefly recent river gravels, new deposits being discovered as old ones were exhausted. The quartz veins which are iron pyrite bearing, and occur in highly inclined crystalline schists, are exploited on a very moderate scale, but with the introduction of improved methods and machinery these will doubtless be more thoroughly developed and become an important source of gold. Russia, in 1822, produced \$585,703 worth of gold, and this output increased gradually to \$9,000,000 in 1842, since which time it has been gradually increasing, with some fluctuations, until 1891, when the product amounted to \$24,131,500. During the years between 1878-80, inclusive, the annual output exceeded \$28,000,000, and in 1883 dropped to a little over \$19,000,000.

South African Fields. — A most important gold field has been very recently developed in South Africa. This field was discovered in 1884, in the Transvaal, and active operations were begun in 1886, since which time the district has literally jumped into the fourth place as a gold-producer, and promises to reach a still higher position. Here, in nearly vertical strata of sandstones and shales, are beds of conglomerates, varying in colour and texture and being frequently auriferous. Some of these beds are 200 feet wide, separated by thin quartzite partings, both rocks being auriferous. Above the water line the gold is free, but below this it is found in pyrite, and the chlorination process has been intro-

duced for its reduction. It is predicted that this region will continue to rapidly increase its output; and the phenomenal development shown in the following table lends probability to this prediction. The output from the South African gold fields since 1887 is as follows:—

1887	\$755,212
1888	3,817,118
1889	7,834,663
1890	9,515,651
1891	14,414,993
1892	22,128,051
Total	\$58,265,688

Of this output, the greater part comes from one district, the Witwatersrand, which in 1892 produced \$21,190,085, and of the total has produced all but about \$5,500,000. Some gold is found in other parts of Africa, and no doubt this metal will be discovered in the interior if there are any mountains of metamorphic rocks.

Other European and Asiatic Countries.—Although nearly all European countries produce some gold, none besides Russia are of much importance in this respect. Austria supplies some gold as a by-product from the antimony and silver mines. Hungary is of much more importance in this respect, and the greater part of this metal accredited to Austria-Hungary comes from the latter. Here the quartz veins occur in eruptive rocks, usually in porphyry, of Tertiary age. A very little gold is produced in Germany as a by-product from the silver and other mines, but this country is of very little importance in this respect. Considerable gold is smelted in Germany (in 1891, \$2,141,998),

but a large part of this is foreign ore sent for smelting from South America and elsewhere. In Asia, China is next in importance to Siberia, as a gold-producing country, but we know little about its occurrence. Japan also produces some gold, but next to China, British India is most important. There are several gold fields, but only one, the Mysore province is of much importance. Here the ore is found in quartz veins in trap dikes which traverse metamorphic rocks. Between the years 1888 and 1892 the output of India increased from \$650,866 to \$2,955,620, the greater part of which came from Mysore.

South American Countries. — South America, which, during the sixteenth and seventeenth centuries, was of such importance as a source of the precious metals, has fallen in rank, and is now of little importance in influencing the world's supply, although there are still good stores awaiting development when the social conditions become more stable. At present, Colombia and Chili are the only important gold-producing countries on this continent; but Peru, Brazil, and Bolivia each produce some. Since 1537 Colombia has had an average annual output of gold exceeding \$1,000,000, and often exceeding \$3,000,000. More gold has come from this country than from any other in South America, — between the years 1537 and 1891 the product having amounted to nearly \$900,000,000. Brazil has produced gold since the seventeenth century, and its total output has been not far from \$700,000,000 or \$800,000,000. Between the years 1741-1760, the average annual output exceeded \$9,000,000, although it is now less than \$1,000,000. Bolivia, although a producer of gold since 1545, has never had a great output, the annual average rarely exceeding \$1,000,000; but the total

production since 1545 is probably not far from \$200,000,000. The annual output of gold in Chili since 1545 has frequently exceeded \$1,000,000, but Peru has been of less importance. Before the discovery of America, there was considerable gold in circulation in both Europe and Asia,¹ the supply having come chiefly from the latter continent. Soon, however, the New World became the source, and until the present century the supply came chiefly from South America. It is probable that since 1545 considerably more than \$2,000,000,000 worth of gold have been produced in South America. The mode of occurrence of this metal in these countries is very similar to that of the gold elsewhere, and needs no especial description.

Mexico and Canada.—Mexico has been a surprisingly unimportant producer of gold; but when the similarity of the Mexican and Cordilleran geology is considered, we are forced to conclude that this is due, not to the lack of supply of gold, but rather to the character of the people and their failure to discover and work the deposits which must exist. The country has never produced much; but when the industrial conditions of this republic have been improved to the modern standard, and inaccessible regions have been opened to exploration, it may be expected that a development of mineral wealth very much like that of our own country will result. Very nearly the same remarks hold for Canada, although this country is somewhat in advance of Mexico. In 1863 Canada produced over \$4,000,000 worth of gold, but the output has steadily decreased since then to only \$925,486 in 1891. At present only a small supply comes from the

¹ One estimate places the amount in circulation in Europe in 1492 at \$193,000,000, and in Asia, \$1,500,000,000.

western provinces and from Nova Scotia, where the gold is found in the Cambrian slates and quartzites in iron pyrite bearing quartz veins. The Canadians have been remarkably tardy in exploring their western reserves, but the little exploration, which has been done has shown the existence of valuable deposits of the precious metals. Since gold is found in all of the states from Mexico to Canada, including the border states, Montana, Idaho, and Washington, and also in Alaska, it may be safely predicted that the intervening territory is also gold-bearing. As yet no important developments have been made, but no doubt the next fifteen or twenty years will witness marked changes in this respect.

Origin of Gold Deposits.—In review, attention should be called again to the remarkable uniformity of occurrence of gold. Perhaps the greater part of the supply comes from gravels of Tertiary or Recent age, formed from the disintegration of gold-bearing rocks and veins, and accumulated by reason of the greater specific gravity and durability of the gold. Allied to these deposits is what is perhaps the third most important mode of occurrence; namely, in consolidated gravels of an age greater than the Tertiary. These were, prior to the development of the South African gold fields, illustrated in Australia by the gold-bearing Carboniferous conglomerates, in the Black Hills by the auriferous Cambrian sandstone, and by other similar deposits elsewhere; but now, owing to the development of the South African fields, this class of gold occurrence has become of great importance. Whether these conglomerates are of marine or river origin cannot be said, although it seems probable that future studies will prove that they were originally river gravels worked over by the sea. Our information concerning these fields is

extremely meagre; and any statement of origin must, therefore, be tentative. Still, their apparent uniformity of extent indicates marine origin, and the quantity of gold suggests the intervention of rivers; for although it is possible that they may have resulted from the destruction of gold-bearing rocks by the ocean waves, it seems much more probable that they represent a deposit, not unlike the auriferous gravels of California, hurriedly worked over by a sea encroaching upon a sinking land.

The second most important mode of occurrence, or perhaps even the most important, is in auriferous-quartz, associated with iron pyrite. There seem to be two types of this occurrence, the one connected with eruptive rocks, the other with sedimentary strata; and in both cases segregation appears to be the method of accumulation. There can be little doubt that the original condition of the gold was in disseminated form in eruptive rocks and that when associated with eruptive rocks these were generally the immediate and primary source. Where bedded with and occurring in sedimentary strata, such as slates, it is very probable that the gold was placed first in the slates by the disintegration of eruptive or other gold-bearing rocks, and later gathered together from this secondary source. Since gold occurs disseminated in eruptive, sedimentary, and metamorphic rocks, it is natural to expect that it will be found in other classes of deposits than those of segregation origin. The author knows of no case where any other origin than that of segregation is proved, in which gold is the primary product: but the fourth important source of gold — namely, that of association with deposits of other metals — furnishes illustrations of this class of deposits which are *gold-bearing*.

Why gold, as the primary ore, is not found in other modes of occurrence than segregation (excepting the mechanical) is difficult to explain, although it may be due to the fact that this metal forms practically no combinations with mineralizers, and, being nearly insoluble, is taken into solution only in small quantities, and forms, therefore, but a small proportion of the mineral contents of those veins in which the minerals are more soluble. During metamorphism the agents at work are more powerful, and gold may therefore be segregated, together with iron pyrite, quartz, and other minerals in smaller quantities. In any event there is an intimate relation between gold, quartz, and iron pyrite. This theory is offered without insisting upon its accuracy, since the true solution of the problem may depend upon changes and agencies much more difficult of explanation.

Uses of Gold. — Gold is used almost exclusively for a medium of exchange and for show utensils and ornaments. The brightness of the metal attracted the attention of the early people and savages, who made ornaments from it. Its rarity has added to its value for this purpose and has caused gold to be adopted as a medium of exchange, in and between nations, since very early times. In a rough way gold was used for this purpose even in Homeric times, and when Cæsar invaded Great Britain he found gold coins in circulation among the Britons. Aside from these uses, gold is employed to a considerable extent in dentistry and in an alloy for the better class of gilding; but ordinary gilt paper contains no gold.

In the arts⁴ the use of gold depends upon its brightness, freedom from tarnish, and remarkable ductility and malleability, which permit it to be easily worked. Pure twenty-

four carat¹ gold is entirely too soft for use, and all that we use is alloyed with other metals. Even free gold in nature is never pure, but generally has from eight to ten per cent of silver in alloy. By alloying with silver and copper the coinage and ornamental gold is made harder, but this is rarely more than eighteen carat gold, and usually much less. Coloured gold, which is sometimes used in fancy jewelry, is made by alloy with different metals. With copper a dark yellow and reddish yellow is produced, the intensity of the colour varying with the percentage of copper. Silver and gold make a greenish and pale yellow metal, and iron gives to gold a grayish colour. An extremely small percentage of lead makes gold brittle and destroys its ductility, and an alloy of gold, palladium, silver, and copper makes a brownish red compound which is so hard that it is used for bearings in fine watches.²

It is in coinage that gold finds its most important use, and it is a striking fact that from the very earliest times this metal has remained of value for this purpose, notwithstanding the remarkable fluctuations in production. When gold began to be produced abundantly from California and Australia, in the decade following 1850, it was predicted that this would necessitate a reorganization of the currency of the world. During the decade 1831-40 the mean annual

¹ Gold alloys "are considered as consisting of so many carats to the unit, the pound or half pound being divided into twenty-four carats, each of which contains twelve grains. What is termed eighteen carat gold is a unit of twenty-four carats of alloy containing eighteen carats of gold and six of copper." — BRANNT, *Metallic Alloys*, p. 331.

² Brannet's *Metallic Alloys* is a valuable reference book for a description of the alloys of different metals, and Hirsch's *Mixed Metals* will also be found of value in this connection.

product of gold in the world was 20,289 kilogrammes, during 1841-1850 the annual average was 54,759 kilogrammes, and between 1851-1855 the average was 199,388 kilogrammes per year. But all the gold produced has been easily absorbed, partly because of the increase of business between nations, and partly by reason of the increasing demand for gold in the arts. Whereas a half-century ago only the wealthy could afford gold utensils and ornaments, now these, either in plated or solid form, find their way among even the poorer classes.

The gold coinage of the mints of the United States has fluctuated remarkably since the Union was formed. Before 1833 it reached \$1,000,000 in only one year (1820), but since then more than \$1,000,000 dollars have been issued each year. Since 1850 the coinage has never, in any one year, fallen below \$14,000,000, and in 1863 it reached \$83,000,000, and in 1881 \$96,000,000. In 1892 the gold coinage amounted to \$34,787,222.50. The four leading gold-coining countries in 1891 issued gold as follows: Great Britain \$32,720,633, United States \$29,222,005, Australia (considered as a whole) \$26,389,044, Germany \$14,277,220. No other nation issued more than \$4,000,000 of gold. In 1889 the United States exported nearly \$51,000,000 of gold, of which \$38,000,000 was domestic. In 1892 over \$76,000,000 of gold were exported, and \$17,000,000 imported. These figures show nothing with reference to the output of the country, but they do show the great amount which is used for coinage, and the way in which gold passes from one country to another by reason of slight changes in value or other economic causes. Much of the gold coined in any one year is recoined gold.

Production of Gold. — The following tables give some instructive statistics for the gold production of the states, the United States, and the world: —

PRODUCTION OF GOLD IN THE VARIOUS STATES OF THE UNITED STATES.

	1877.	1880.	1885.	1887.	1891.
California .	\$15,000,000	\$17,500,000	\$12,700,000	\$13,400,000	\$12,600,000
Colorado .	3,000,000	3,200,000	4,200,000	4,000,000	4,600,000
Dakota .	2,000,000	3,600,000	3,200,000	2,400,000	3,550,000
Montana .	3,200,000	2,400,000	3,300,000	5,230,000	2,890,000
Nevada	18,000,000	4,800,000	3,100,000	2,500,000	2,050,000
Idaho .	1,500,000	1,980,000	1,800,000	1,900,000	1,680,000
Oregon	1,000,000	1,090,000	800,000	900,000	1,640,000

The territories next in rank, all producing between \$500,000 and \$1,000,000, are Arizona, New Mexico, Alaska, Utah. The only eastern state producing more than \$100,000 is South Carolina (\$125,000). California produces more than one-third of the gold of the country, and about one-tenth of the product of the world. Since 1881 there has been a decrease in the output of this state, and this is in part attributable to the legislation adverse to hydraulic mining. Colorado is gradually increasing its output of gold, and Dakota fluctuates, but remains about uniform with a slight increase. Montana reached a maximum in 1887, and its output has since declined, while Nevada shows the effect of the abandonment of a part of the Comstock Lode, by a remarkable decrease between 1878 and 1880.

OUTPUT OF GOLD FROM THE UNITED STATES.

VALUED AT \$20.67 AN OUNCE.

1847	\$889,085
1848	10,000,000
1849	40,000,000
1853	65,000,000
1859	50,000,000
1862	39,200,000
1866	53,500,000
1870	50,000,000
1880	36,000,000
1890	32,845,000
1892	33,000,000

The total production of gold in the United States since 1792 to the close of 1892 is \$1,969,692,949, of which all but \$24,536,767 has been produced since the beginning of 1848. Since 1853 there has been a gradual decrease in the output, with some fluctuations. The United States, since the beginning of 1848, has produced nearly as much gold as South America since 1533. It has exceeded the output of Australasia by over \$300,000,000, and has greatly exceeded the output of Russia since 1822. We may, therefore, safely claim for the United States the first rank as a gold-producing country.

PRODUCTION OF GOLD IN THE WORLD, 1880-1891.

	1880.	1882.	1884.	1886.	1888.	1891.
United States	\$36,000,000	\$32,500,000	\$30,500,000	\$35,000,000	\$33,175,000	\$33,175,000
Australasia . . .	28,765,000	31,955,017	24,244,000	26,125,000	28,560,660	31,399,000
Russia	28,551,028	23,867,935	21,874,000	20,518,000	21,302,000	24,131,500
Africa	1,993,800	1,993,800	830,000	1,438,000	4,500,000	14,199,600
China . . . . .	.	....	6,222,000	3,650,000	9,000,000	5,330,000
Colombia	4,000,000	3,856,000	3,856,000	2,500,000	3,000,000	3,472,000
British India . .	....	....	....	421,600	676,563	2,495,000

The countries producing between \$1,000,000 and \$2,000,000 of gold, in 1891, were, in the order of their importance, Canada, Chili, Austria-Hungary, British Guiana, Venezuela, Mexico. The output of gold from the German smelters, in 1891, was \$2,141,998, but this was partly from foreign sources, and we have no statistics for the gold output of the mines. Of the total production of gold in the world during 1891, which amounted to \$125,299,700, the United States supplied 26.4 per cent, Australasia 25 per cent, Russia 19.3 per cent, and Africa 11.3 per cent. Together these four regions produced 82 per cent of the gold product of the world, and the United States and Australasia produced more than one-half of the world's supply.

TOTAL PRODUCTION OF THE WORLD.

1849	\$27,100,000
1853	155,500,000
1869	125,000,000
1875	111,000,000
1880	108,000,000
1883	97,000,000
1885	106,000,000
1889	120,000,000
1891	125,299,700

The mean annual product of gold prior to this time, in kilogrammes, valued at \$664.60, was, for the period between 1493-1520, 5,800 kilos.; between 1741-1760, 24,610 kilos.; between 1811-1820, 11,445 kilos.; between 1831-1840, 20,289 kilos. Between the years 1856-1860 it increased to 201,750 kilos.

Platinum Group.

Occurrence of Platinum. — Platinum¹ is of little importance as an ore in the United States. Occasionally, however, it is found in the gold-bearing gravels, but as it does not amalgamate with the mercury, it is not saved, and it does not seem to be in sufficient abundance to pay for separate mining. Nevertheless, some is produced each year, and in 1890 about \$2500 worth was produced chiefly from the auriferous gravels of California and Oregon. Since no especial efforts have been made to save it, we have no means of knowing whether it is present in sufficient abundance for separate mining. The prospectors do not know the value of the black sand, nor are they always able to distinguish it from less valuable ores; and it is, therefore, not unlikely that deposits may yet be found.

The supply of platinum comes chiefly from Russia, where it occurs in gravels, probably originally auriferous, on the Siberian side of the Urals, where it was first discovered in 1819. Since serpentine is usually near at hand, and the placers increase in richness as this rock is approached, and since the metal has been found in this rock, it seems probable that this is the source. This mode of occurrence of platinum and the association with serpentiferous rocks² prevails also in other platinum-producing regions. Platinum is always

¹ Descriptions of the platinum group and their modes of occurrence will be found in *The Mineral Industry* for 1892, Rothwell, pp. 373-397, and in the Eleventh Census volume on *Mineral Industries*, pp. 341, 342.

² Serpentine is generally a metamorphic rock resulting from the decomposition and alteration of olivine-bearing as well as from other rocks. The source is generally, though not always, an igneous rock, and the platinum may be a product of this metamorphism.

alloyed with the other metals of the platinum group, iridium, osmium, palladium, etc., and with iron, the amount of platinum varying from 50 to 80 per cent. In Russia, as well as in other platinum-producing regions, chrome iron¹ and iridosmium are associated with the metal.

Next to Russia, Colombia is the most important region as a platinum-producer, and about 125 kilogrammes are annually supplied from there. Some platinum is also supplied from Brazil, Borneo, New South Wales, New Zealand, and British Columbia, about \$10,000 worth having been produced from the latter region in 1891. In all of these countries the platinum comes from auriferous gravels, and in some regions it is also found alloyed with gold. A unique occurrence discovered in Canada a few years ago promised at first to produce platinum, but as yet has not done so. This occurrence at Sudbury, Ontario, was an arsenide of platinum found in the nickel mines of that region.

Uses. — Platinum is tin-white in colour, very heavy, extremely ductile and malleable, and melts only at a very high temperature ($1750^{\circ}\text{C}.$). It is very permanent, and only a few substances attack it. The first use of the metal was to adulterate gold, but until very recently its most important use was for crucibles and other chemical apparatus in which a high melting-point and chemical permanence are needed. It has been used for coinage in Russia, from 1828 to 1845, but in the latter year its coinage was suspended and the coins called in, because of its increase in value and the con-

¹ It will be noticed by reference to the chapter which considers chrome iron, that this ore is always found associated with serpentine, and therefore this association of the two minerals is also suggestive of origin from serpentine.

sequent shipment of the metal out of the country. At present a considerable part of the platinum used in this country is made into pins for holding artificial teeth to the plate, this being the only available metal which will withstand the heat of baking. Some platinum is also used in dentistry for filling teeth. Incandescence electric lamps and other electrical apparatus call now for the greatest supply of platinum in the United States, where more of this metal is used than in any other country. Some is also used in photography and in jewelry. It is estimated that in 1891 the United States consumed 1172 kilogrammes in electrical apparatus; 1088 kilos. in dental work; 280 kilos. in sills and retorts; and 92 kilos. in crucibles, dishes, etc.

Since Russia practically controls the supply of platinum, the prices fluctuate greatly. In 1867 the metal was worth \$4.40 an ounce; in 1889, about \$8.00 an ounce; then, by a corner in the market, the price ran up, in the autumn of 1889, to \$17.50 an ounce. In October, 1892, the price fell to \$7.50, but in December rose to \$10.50. These fluctuations in price are not due to a variation in demand or supply, but plainly show the intervention of some manipulation on the part of those who control the supply.

Production. — The production of platinum in Russia has, since 1878, kept above 2000 kilogrammes a year, but the output has fluctuated greatly. During 1886, 4316 kilos. were produced; in 1889, 2634.8 kilos.; in 1891, 4226. Since 1880 the average annual output of Columbia has been about 125 kilos. a year; from Canada in 1891, 65.4 kilos. were produced; and from the United States, 14 kilos. From Colombia, since 1737, not far from 18,000 kilos. have been supplied, and from Russia, since 1824, about 113,000 kilos.

Other Metals of the Platinum Group. — This grouping is based upon the fact that several metals, iridium, osmium, palladium, ruthenium, and rhodium, are associated with platinum and have the same general properties as elements. Iridium, a steel-white, extremely hard metal, next in specific gravity to osmium, is supplied partly from its alloy with native platinum, and partly from the iridosmium which occurs in the platiniferous gravels. It is used for pen points and in jewelry (on account of its hardness), in photography, and recently in metal-plating. Osmium, which is the heaviest known metal, comes from the same sources as iridium, and in the form of iridosmium is used for pointing tools and pens. Palladium, a brilliant silver-white metal, which also occurs with platinum, is on account of its high price very little used, although it has all the attractiveness of silver without its habit of tarnishing. A number of small uses are made of this metal, and recently in alloy with copper and iron it has been introduced into the manufacture of watch springs and balance wheels, for which it is especially well adapted, since it is not capable of being magnetized, and is, therefore, valuable for watches carried in electric plants. The two other metals of the platinum group, ruthenium and rhodium, are not used in the arts, but are practically chemical curiosities.

CHAPTER VIII.

SILVER.

General Statement.—Unlike gold, there is a wide variation in the mode of occurrence of silver, and the ores of this metal are both numerous and varied. Native silver, although not common, is frequently found, but the most frequent occurrence is in chemical combination with mineralizers. The affinity of sulphur for silver is noticed in all silverware, which, when sulphurous gases are present, immediately tarnishes, forming a sulphide. Consequently, in nature, silver ores are prevailingly sulphides such as argentite, pyrargyrite (a sulphide with arsenic), or a sulphide of some other metal with silver. Thus the greater number of occurrences of the sulphide of lead, galena, much of the sulphide of zinc, blende, and the copper sulphide, chalcopyrite, are argentiferous. As a chloride, bromide, and in other combinations, silver is not uncommon, while a considerable percentage of the supply comes from gold, where it is frequently present in alloy to the amount of eight or ten per cent.

The consideration of silver forms, therefore, a complex subject, and it might with propriety be discussed either with gold or together with lead, which shows how arbitrary is the economic classification starting with the metal as the primary basis for a division of this part of the subject of economic geology. This will become more apparent in the

later pages of the chapter, since this metal illustrates fully the fallacy of such a classification. Before the discovery of South America, the world's supply of silver came chiefly from argentiferous galena, and although many mines of true silver ores have been discovered in the two new continents, it is still true that a large part of this metal comes from this source. A very few ounces of silver to the ton generally makes galena an ore capable of profitable extraction, in places where, owing either to difficulties of mining or lack of transportation facilities, it could not otherwise be mined. In many mines the lead just about pays the expense of extraction, and the silver thus won is profit.

Silver Mines in the United States.—Practically all the silver of the country is produced in the Cordilleras, and, as will be seen by reference to the table of production at the close of the chapter, nearly all of this metal at present produced in the United States comes from the two states Colorado and Montana and the territory of Utah. A very few localities from this section are chosen for description, and these are the mines which are best known.

Comstock Lode.—Nevada has been, until within a few years, pre-eminently the silver-producing state of the Union, although, at present, it is fifth in rank of importance. Whereas, in 1877, the output of silver from this state was \$26,000,000, in 1891 it produced but \$4,551,111. This decrease is due mainly to the abandonment of parts of the remarkable Comstock Lode, a mine which has never had a parallel in the history of mining. On the basis of the development of this mine a large city was founded, and a state literally created. With the abandonment of the

lode the state has decreased in population and the region practically reverted to its original condition.

The discovery and development of the Comstock Lode exerted a disturbing influence on the monetary world. Discovered in 1858, it was a wonderful producer until 1877, when it rapidly declined. The history of this mine has been so full of interest, and withal so remarkable, that a summarized statement of the more important events is given here.¹ It has been a history composed of a series of chapters of obstacles and of unusual difficulties which were sometimes insurmountable. These began with the discovery of the vein, when, by a series of frauds, the lode changed hands and the titles became confused, giving the excuse for long-continued and disastrous litigation. When discovered, the region was an utter wilderness, occupied by savages; there was no fuel at hand, no timber for supporting the roofs of the tunnels, wages were extraordinarily high, and there were practically no supplies and no available water. Eventually a water supply for Virginia City was obtained from a distance of twenty miles, at an expense of over \$2,000,000. It was necessary to transport timber, supplies, and machinery across a long stretch of desert country, and the progress of development was thus very seriously retarded.

When the mines were well under way, and prosperity seemed, at last, to be at hand, litigation began. Fires destroyed the valuable timber in the mines, but above all, reckless extravagance of management interfered with the normal development of the lode. Before the close of 1861

¹ Lord, *Comstock Mines and Mining*. Monograph U. S. Geol. Survey, Vol. IV., 1883.

stock companies were formed, with a capitalization of more than \$60,000,000, but notwithstanding the wonderful output of the mine, the stockholders realized but little from their investment. During the year 1863 water was added to the other difficulties, and the mines were flooded as the result of a break in the clay wall. From this time on, there was maintained a constant battle with water, and this led, in 1871, to the beginning of the famous Sutro tunnel, which was commenced with the intention of constructing a drainage-way for the water in the lower part of the mines. This tunnel, which is 20,489 feet long, and was constructed at a cost of \$2,000,000, was not finished until 1878, and it was then too late to be of service, since the mine was far below the level of the tunnel.

During the construction of the tunnel, and in the lower parts of the mine, a novel difficulty was encountered. Here the heat became intense and almost unbearable. In the Sutro tunnel the temperature rose to 110°–114°, and even the slightest exertion was so exhausting that, although cold air was constantly blown from the surface, it was necessary to change the force of miners four times a day. In the mine at the 3000-foot level, water, at a temperature of 170°, poured in, and the lower workings had to be abandoned. Normally, the temperature of the earth increases as the depth is increased, but many mines have gone below the level reached by the Comstock without having experienced excessive temperatures. Here, therefore, some abnormal cause must be sought, and although it has been suggested that the heat is supplied by the decomposition of feldspar in the country rocks, the most probable explanation is the presence of some intruded igneous mass which has not yet had time

to cool. Any mine may encounter a similar phenomenon, but it is hardly probable that many will.

PRODUCTION OF GOLD AND SILVER FROM THE COMSTOCK
LODE.

YEAR.	GOLD.	SILVER.	TOTAL.
1859	\$30,000	....	\$30,000
1861	2,450,000	\$1,050,000	3,500,000
1864	6,400,000	9,600,000	16,000,000
1869	2,962,231	4,443,347	7,405,578
1872	4,894,560	7,341,840	12,236,400
1873	8,668,793	13,003,187	21,671,980
1875	10,330,209	15,495,312	25,825,521
1877	14,520,614	21,780,922	36,301,536
1878	7,864,558	11,796,836	19,661,394
1879	2,801,394	4,202,091	7,003,485
1881	430,248	645,372	1,075,620
1884	1,261,314	1,577,438	2,838,752
1886	2,054,920	1,681,298	3,736,218
1888	3,167,209	4,458,058	7,627,267
1890	2,002,000	3,087,000	5,089,000
1891	1,200,000	1,900,000	3,100,000

Another unique feature in the Comstock is the fact that the ore is distributed with marked irregularity, and if it were not of very high grade in a few places, it could never have been worked. Many companies have spent millions of dollars without raising any ore, but have explored barren rock with the aid of frequently levied assessments, always in the hope of finding a "bonanza." At other times rich pockets, which have produced wonderful results, have been encountered. In all the explorations in this lode it was estimated, a few years ago, that there were constructed over 150 miles of tunnels. Among the several rich pockets found in

the Comstock, the so-called Great Bonanza, which was discovered in 1873, was the most remarkable. The rock removed carried as high as \$93 to \$632 of gold and silver per ton, and from 1873-1878 \$60,732,000 of these metals were produced from one mine alone. During the years 1875 and 1876 this pocket produced over \$16,000,000 a year, its influence being noticed in the table on page 184, which shows the output of the lode. From 1859 to 1890 the total product of the lode was fully \$325,000,000.

The Comstock Lode¹ is a belt of quartz about 10,000 feet long and several hundred feet broad, showing slight undula-

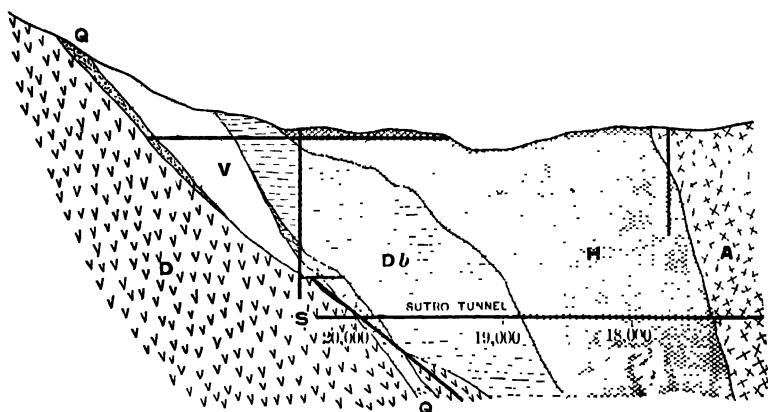


FIG. 18.—Cross-section of Comstock Lode, Nevada. *D*, diorite; *Db*, diabase; *H*, hornblende andesite; *A*, augite andesite; *S*, Sutro tunnel; *V*, vein matter; *Q*, quartz. (After Becker.)

tions and at each end branching and disappearing. It follows approximately the contact of two igneous rocks (Fig. 18), a diabase and a diorite, and dips east of south at

¹ The geology of this district is fully described and ably discussed by Becker, *Geology of the Comstock Lode*, Monograph, U. S. Geol. Survey, Vol. III., 1882.

an angle of 33° – 45° . There is abundant evidence of faulting by the presence in the vein, of horses, breccia, slickensides, etc., and this led Richtofen, who first studied the lode, to consider it a true fissure vein; but more recent studies have shown that it is not entirely a fissure vein, but in part an ore channel following the contact of the two igneous rocks. The hanging wall is diabase, and the foot wall is diorite for about three-fourths of the distance, with slates for the remainder.

As has been stated, the ore is extremely irregular in distribution, occurring in bonanzas, sometimes of marvellous richness, occasionally carrying several thousand dollars to the ton, but only in spots assaying above the \$15 to \$20 to the ton, which is necessary to make the mine pay. It is found that near the diorite the ore is usually poorer, and that here the proportion of gold increases. The ore minerals are often so disseminated that they elude investigation, but they are probably argentite and native gold and silver.

Some interesting results have been obtained from the careful studies of the lode with reference to its origin. The region is one of great geological complexity, metamorphic rocks and granites being traversed by the following igneous rocks: diorites, quartz porphyry, two ages of diabase, two ages of hornblende andesite, augite andesite, and basalt. Analyses have shown that in the diabase and diorite the metallic elements found in the vein are present in disseminated condition; and a study of the rocks has resulted in proving that the diabase is very much decayed and altered near the lode. Moreover, the decomposed diabase contains much less metal than the fresh rock, but the proportions of the two metals found in the vein are the

same in the fresh diabase. Everything indicates that the vein has been very recently formed, that very little erosion has taken place since its formation, and that the source of the metalliferous solutions is not very deep seated, — a conclusion which is supported by the presence of heat in the lower parts of the mine. Becker has, after a careful study of all the conditions, concluded that the history of the lode has been, first a faulting of the rocks, then the percolation of water through the diabase, producing an alteration of the minerals and causing the extraction of gold and silver, principally from the augite, and finally an uprush of heated waters accompanied by the deposition of quartz, silver, and gold. The variations in the amount and character of the ore are due, partly to the variations in supply, partly to the influence of the neighbouring rock.

*Eureka District.*¹ — A second important silver-producing district in Nevada is the Eureka, in the eastern part of the state. This district was discovered in 1864, and active operations begun in 1868. It is an argentiferous galena vein, and up to 1882 the output was not far from \$60,000,000 of precious metals and 225,000 tons of lead. There are two mining areas, Prospect Hill and Ruby Hill, in which the mode of occurrence is very similar. The rocks, which are tilted Cambrian limestones and shales, are folded, and while the shales have bent without fracturing, the limestones have been crushed and brecciated. There are also distinct faults, some of which have a considerable displacement; and crossing these stratified rocks are intrusions of quartz porphyry and rhyolite. In fissures, crevices, and caves in the crushed

¹ This district has served as the subject of a valuable memoir by Curtis, *Monograph*, Vol. VII., U. S. Geol. Survey, 1884.

limestone, the argentiferous galena, with some gold, is irregularly distributed through a gangue of calcite and iron oxide (Fig. 19). Down to the water-line the ore is oxidized to a silver-bearing carbonate and sulphate of lead. Both in richness and in distribution the ore is irregular,

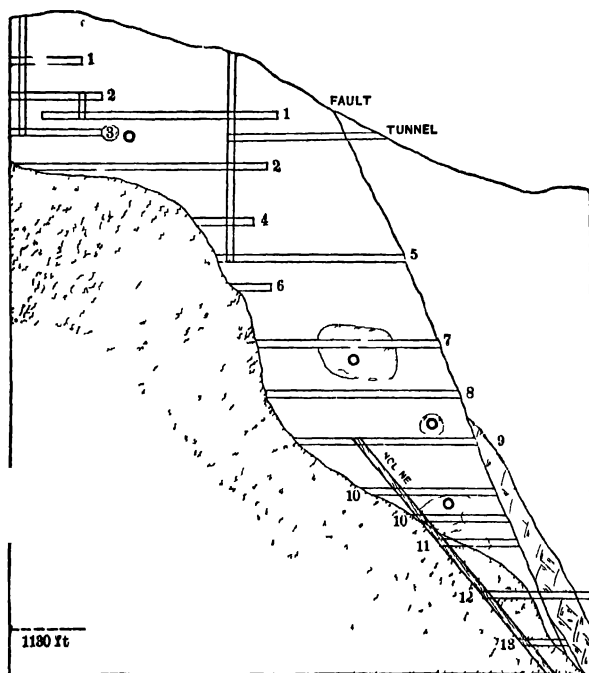


FIG 19. — Cross-section of Eureka Consolidated Mine, Nevada Figures refer to levels Dotted portion, quartzite, unshaded part, limestone, small portion cross-lined, shale, ore, (O) (After Curtis)

there being many areas of lean ore and frequent rich pockets. Sometimes the galena carries from \$100 to \$150 of silver and from \$1 to \$10 of gold to the ton.

Apparently, during the upheaval of the region, ore-bearing solutions entered the rock by the path of least resistance,

sometimes passing along faults, but most commonly entering the crevices between the crushed limestone. It was thought that possibly the limestone itself might have furnished the ore, but analyses have shown that the quartzite, shale, and limestone have only minute quantities of silver, and hence this seems improbable. The most probable source is the intruded rhyolite, from which the ore may have been derived either by solfataric action or by infiltration. In places chambers have been dissolved out and later partly filled, and in others there is evidence of a replacement of the limestone.

Other Silver Mines of the United States.—While Nevada has been decreasing its output of silver, Colorado has, since 1877, been rapidly increasing, and this state is now, as it has been for a number of years, the chief silver-producing state of the Union. There are in this state many mines, chiefly, though not entirely, of argentiferous galena, and, also, there are many modes of occurrence. The two most important mining districts in Colorado are at Leadville and Aspen,¹ from both of which argentiferous galena is produced. The Molly Gibson mine of the Aspen district is at present producing native silver in a pink barite gangue, and the ore in places is nearly pure silver, the assays in some cases giving from 2000 to 12,000 ounces. Recently a mining camp at Creede has become important, and its output of 5,000,000 ounces of silver, in 1892, is the reason for the increased output of the state in that year, in spite of the fact that parts of the Leadville vein had begun to decrease their output. The deposits are apparently fissure veins in

¹ The geology of the Aspen district is described by L. D. Siver in *Engineering and Mining Journal*, Vol. 45, 1888, pp. 195, 196, and 212.

igneous rocks. The Leadville district, which is one of the most important mining districts in the country, is described in the chapter on lead, and may be considered to illustrate one of the modes of occurrence of silver. In Colorado nearly every mode of occurrence and nearly every ore of silver is found.

In Montana, the state second in importance as a silver-producer, very nearly the same conditions exist; but here a considerable part of the supply is extracted from the copper at Butte. The veins of this region are altogether quite remarkable. There are two closely associated series of veins in one of which the predominating ore is copper, while in the other silver sulphides are common. Practically no copper occurs in the latter and the gangue is rhodonite, a silicate of manganese, although this metal is not found in the copper veins. Thus, although so closely associated, these veins are widely different in character, pointing to a deep-seated origin probably at different times.

Utah has also increased its silver output. Nearly one-half of the supply of this territory comes from the mines at Park City in Summit County, although there are several other veins producing large amounts of silver. The ore is a silver lead ore, and, since the beginning of 1887, more than 3,000,000 ounces of silver have been produced each year. The Ontario mine of this district is in a well-defined fissure traversing quartzite irregularly. A mass of porphyry occurs at no great distance, and in places actually forms the hanging wall. Below 400 feet the ore is undecomposed galena, blende, and copper sulphide rich in silver. There are also in this territory mines of chloride of silver. From Idaho, which is now the fourth state in order of importance as

a silver-producer, the greatest amount of ore is obtained from the Cœur d'Alene mine,¹ which has a low-grade argentiferous galena exposed in great quantities and easily mined. This district, which, in 1886, produced only 116,246 ounces of silver, in 1891 had an output of 1,825,765 ounces.

Considerable silver is mined in Arizona, and here also much of it is from argentiferous galena. Of the several districts, that at Tombstone in Cochise County has attracted most attention. According to Phillips² the ore here is bedded chiefly in limestones, which are stratified with shales and quartzites, and the series is folded, faulted, and crossed by dikes of porphyry. The ore follows the bedding for a distance then breaks across it nearly vertically, following either a crack or a fissure, and again becomes horizontal. A variety of ores occurs in the different mines, but, in general, in the limestone it is silver-bearing lead, although from some of the mines a chloride of silver and free gold are obtained. New Mexico has a number of silver occurrences; but the production of this metal in the territory is not as great as it might be with better transportation facilities. There are remarkably few silver mines in California, and a large part of the output credited to that state is obtained as a by-product from the gold. This apparent poverty in silver mines in California is no doubt partly due to the fact that the energies and available capital of the state have entered into gold production; but it is chiefly due to the general absence of silver deposits in the Sierras and Coast Ranges of the state.

¹ The geology of this district is described by Professor J. E. Clayton in the *Engineering and Mining Journal*, Vol. 45, 1888, p. 108.

² *Ore Deposits*, pp. 536-541.

These few districts, selected from many as the best known, illustrate the wide variety of occurrence of silver in this country; and, when taken in connection with the description of foreign mines, and the silver-lead deposits, these will serve to indicate the manner in which silver occurs. There is no uniformity of occurrence, but the ore may be found in almost any position with relation to the surrounding rocks. Nevertheless, one notices a striking uniformity of association with igneous rocks.

As to distribution, practically all of the supply of silver in this country comes from the Rocky and Sierra Nevada mountains. Aside from here and the Black Hills, the only state which produces any considerable amount of this metal is Michigan, which, in 1891, had an output of less than \$100,000. A few thousand dollars' worth of silver comes annually from the southern Appalachian states, partly from the gold ores and partly from argentiferous galena. Throughout the belt of Archean metamorphic rocks numerous silver mines of this nature have been opened at various times, but they have rarely paid, since the veins are usually small and the percentage of silver low. Some of them, if situated in Europe, where the methods of mining are more economical and of reduction more saving, might be made to yield returns; but, in this country, where labour is high and where we are accustomed to extravagant methods of mining and rapidly made fortunes, these deposits are not exploited. It is possible that in the future some of these may become profitable; but while such immense returns are made from the western states this is not probable.

• The most striking features of the distribution of precious metals in this country is their remarkable development in

the west and their practical absence east of the Rockies and the Black Hills. The probable reasons for this are suggested in an earlier chapter.¹ There are no statistics at hand for the relative importance of the different ores of silver; but it is evident that in this country an important part of the supply of this metal comes as a by-product from lead, zinc, copper, and gold mines. From these sources, by the advances in metallurgical methods, the production of silver is every year increasing.

Mexico, Central America, and Canada. — Next to the United States, Mexico is the most important silver-producing country. There are, in this republic, many lodes which have been worked for a long period of time, many recently opened, and many which, owing to the condition of the country, have not been developed. One of the famous old veins is the ore channel of Guanajuata, the Vete Madre, which occurs at the unconformable contact between Devonian slates and Triassic sandstones, and has a width of from 200 to 300 feet. The ore is principally argentite and native silver in a gangue of quartz and calcite. Another famous vein is the Vete Grand in the state of Zacatecas, which is a true fissure vein with a width of about twenty-five feet. Both of these veins, although not worked to a great depth, are decreasing in quality, and consequently in output; but other veins are increasing, and new mines are being opened, so that the total output of the country does not decrease. The Mexican mines have usually a gangue of quartz or calcite, with either complex or simple sulphides for ores, many of them being argentiferous galena, weathered near the sur-

¹ p. 95.

face, to carbonates, etc. The mode of occurrence is very similar to that of this country, the silver-bearing belt being a southern continuation of our own Cordilleras. It is a wonderfully rich district in mineral products, but owing to the unstable condition of the nation, the cost of fuel and timber, and the difficulty of transporting machinery, it is only partially developed.

From 1521 to 1875 Mexico produced \$3,167,096,424 of silver, and since then its yearly output has steadily increased from about \$21,000,000 to over \$53,000,000 in 1891. This has increased the total output to date to nearly \$4,000,000,000. Since the first production of silver in 1521, the annual supply has increased steadily, with some minor fluctuations, and, as the prospects for the future seem equally bright, Mexico may yet take first rank in the production of this metal.

Canada is a very small producer of silver, the principal supply for many years having been obtained from a true fissure vein which crosses the schists, at Thunder Bay, on the shores of Lake Superior. Recently argentiferous veins have been discovered in western Canada, near Kootenay Lake, and this region promises to become an important silver-producing district in the future. Since the Cordilleras extend into Canada, and are silver-bearing to the very boundary, there is every reason to expect its discovery when this region shall have been explored.

Between South America and Mexico the countries of Central America have geological conditions so similar to the regions north and south of them that we may expect to find this an important silver-producing district when the political and social conditions become more advanced.

Already they produce some silver, the output in 1891 having been about \$2,000,000, but we know very little of the geology of these countries, and their mineral resources have never been tested.

South American Silver Mines.—The western countries of South America, which are situated in a southern continuation of the same general region as that of our Cordilleras, shared with Mexico the highest rank, in the production of silver, before the developments of the last thirty years in the United States. At present, this general district holds third rank; and very nearly all of the output comes from the countries which are situated in the Andes. Of these, Bolivia is by far the most important. Here there are a number of large and very rich silver mines, but of these the best known is the Potosi, which is famous for its almost fabulous richness. It was discovered in 1545, and worked continuously until 1809, and since then more or less continuously to 1850. From this mine over \$1,000,000,000 worth of silver has been produced, the output at times having amounted to over \$9,000,000 a year. The occurrence is apparently in a fissure, crossing quartz porphyry and slates, being less productive in the latter. Native silver, pyrargarite, and chloride of silver are the most common ores. During the time of greatest prosperity, this mine caused the development of a large city high up in the mountains;¹ but now the mine is practically abandoned, although, after its long idleness, it is soon to be reopened. At present, the most important mining district in this country is the Huanchaca. Since 1545 the

¹ This town is one of the highest inhabited towns in the world, being at an elevation of 13,280 feet. In 1611 there were 160,000 inhabitants, although now not more than 10,000.

average¹ yearly output of silver from Bolivia has never fallen below \$1,700,000, and for a large part of the time the average has exceeded \$5,000,000. Since 1876 the average annual output has exceeded \$10,000,000, amounting, in 1891, to \$15,488,000.

Next in rank to Bolivia is Peru; and in this country the most important silver mine is the Cerro de Pasco, which was discovered in 1630, and has been worked almost continuously since then. Although this mine has been exploited for 260 years, and has probably produced fully \$300,000,000, the shafts have not extended below 300 feet, and there is probably a greater body of low-grade silver ore exposed in this mine than in any other partly developed vein in the world. In 1841 the output reached nearly \$4,000,000 a year; and since 1788 the annual production has not fallen below \$1,000,000 in any year, excepting when closed during the war of independence (1821-1825). The mine has never been systematically and scientifically developed, although recently explorations have been carried on in the interest of a syndicate; but it seems probable that, on account of the difficulties of transportation and the low grade of the ore, it cannot be worked below the water-line. Even at the present time, the mine is worked by the natives, and the metal extracted by the crude Patio process; and by these means 1,000,000 ounces of silver are annually produced. Below the water-line the ore is a sulphide, and above this it is oxidized, occurring in an easily worked ferruginous earth. Since 1533 Peru has had an annual average output exceeding \$1,000,000, and usually exceeding \$3,000,000, while during the first decade of this century the output exceeded \$6,000,000 a year.

¹ The average being taken for periods of five and ten years.

The third most important silver-producing country in South America is Chili, and here also there are several very notable districts. A very peculiar deposit exists in the Chañarcillo district, where the silver is found in the form of a bromide and chloride, varying remarkably from rock to rock. It occurs in Jurassic limestone, associated with eruptive diorites, and appears to be in part a contact, in part a fissure deposit. The descriptions of South American mines are so meagre, and often contradictory, that very little of value can be stated concerning their geological occurrence.

Chili has not been an important silver-producing country for as long a time as Bolivia and Peru; but since 1840 the product has annually exceeded \$1,000,000, having rapidly increased until 1886, when the output was \$8,727,600, and since then having rapidly decreased, until, in 1891, only about \$3,000,000 were produced. The other countries of South America, excepting Colombia, produce practically no silver; and in that country the supply comes largely from the gold product.

Australasia.—This forms the fourth most important silver-producing district in the world. The supply comes in part from the gold; but there are also mines of silver, with sulphides for ores, and also argentiferous galena mines. None of the countries of this continental area, excepting New South Wales, are of importance in the production of this metal. Here, aside from the silver produced as a by-product in gold mining, the principal district is the Barrier range, where there is an argentiferous lead ore, which produced, in 1892, 13,336,809 ounces of silver and 56,633 tons of lead.

European Silver Mines.—Germany is the leading silver-producing country of Europe, and there the metal exists in

very complex association. True silver mines occur in Silurian schists, in the Andreasberg district of the Harz Mountains, but generally the metal is obtained from the complex sulphides. At Freiberg, in the Erzgebirge, the richest argentiferous galena occurs. Silver is also extracted from the complex sulphides, galena, blende, copper and iron pyrite, at Clausthal, in the Harz; and it is found in the same general association in the Rammelsberg district, which is also in the Harz. In the latter district the veins are bedded and folded with Devonian slates, and in the other mining districts of Germany there are segregated and fissure veins frequently associated with eruptive rocks. Since 1820 Germany has had an average annual output of silver exceeding \$1,000,000, and this has been gradually increasing, until, at present, over \$7,000,000 are produced each year.

In France considerable silver is annually produced, the ore being chiefly argentiferous galena occurring in schists and granites which are crossed by porphyry. Spain contains several silver-producing districts, most of which have argentiferous galena for an ore. The Guadalajara mines occur in gneiss and produce chiefly argentite and ruby silver, with some galena, in a gangue of barite and quartz. In Austria-Hungary the silver is found in very nearly the same modes of occurrence as in Germany, the ore being chiefly argentiferous galena and other complex sulphides. The two most important districts are Schemnitz and Kremnitz. Silver has been produced from the Przibram district, in this region, since the year 843, and some of the mines have descended to a great depth.³ The occurrence in this country is usually in association with eruptive rocks. Since 1830 the average annual output of silver from Austria-Hungary has exceeded

\$1,000,000, and for the last fifteen years the average has been over \$2,000,000.

No other European countries produce more than \$1,000,000 worth of silver annually, but some is obtained in Russia, principally from the gold, and some in Sweden and Norway, where ores of native silver and of silver sulphides occur in metamorphic rocks which are crossed by igneous intrusions. In Great Britain a small amount of silver is extracted from the ores of copper and zinc in Devonshire and Cornwall, as well as from limestones in other parts of the islands, where it occurs in the form of argentiferous galena. The Cornwall and Devonshire mines are either in or near igneous rocks.¹

Origin of Silver.—The remarks made above concerning the occurrence of silver in the United States apply with equal force to the foreign silver veins. In Europe, the metal is found most commonly in the complex sulphides, argentiferous galena, blende, copper pyrite, etc., but sometimes in simple sulphides or with other mineralizers. The same is true of Australia, but here galena is the principal source. The United States and Mexico illustrate the same associations, but in these countries the simple ores of silver are more common, while in South America the larger proportion of the silver comes from ores unassociated with other metals. The greater part of the silver of the world is obtained as a by-product in the mining of other metals, and this is strikingly the case in Great Britain, Germany, and Austria-Hungary, where a great variety of metals come from the same

¹ For detailed descriptions of the mining districts of Europe, and particularly of Great Britain, reference may be made to Phillips' *Ore Deposits*. Davies' *Earthy and Other Minerals and Mining*, *Metalliferous Minerals and Mining*, Davies; and von Groddeck's *Die Lehre von dem Lagerstätten der Erze* also give good descriptions of European statistics.

mine; but no single mineralogical association of silver is so common as that with the sulphide of lead. Next in importance are the simple ores of silver, of which the sulphides are the most abundant, although chlorides and oxides are not rare. A third important source is from gold, with which it is alloyed. Native silver is found, but it is not common except in its alloy with gold. It is a striking fact that the source of a great part of the silver is such that, at its present price, it could not be profitably extracted if the metals with which it is associated were of no value.

For the mode of occurrence no general statements can be made. Perhaps true fissure veins are the most important, although veins of segregation, bedded veins, contact, chamber, replacement, and other modes of occurrence are not uncommon. Silver is not found in placer deposits, for the reason that it is chemically weak, and, under the influence of weathering, loses its metallic character, disintegrates, and is carried away with the lighter and finer particles. The original source of silver is undoubtedly igneous rocks, where it occurs in association with the metalliferous bisilicates, chiefly augite, hornblende, and mica. Consequently this ore is found most commonly near its source; that is, in association with igneous rocks which have been subjected to alteration by the percolation of water charged with substances which give to it a solvent power. But since sedimentary and many metamorphic strata are derived, either directly or indirectly, from igneous rocks (even if it is necessary to trace them back to the original crust of the earth), it is not unnatural to expect to find that such deposits have at times been derived from these secondary sources. Analyses have demonstrated the existence of silver in many sedi-

mentary rocks, but rarely in sufficient abundance to become concentrated, excepting under very favourable circumstances. This is what would be expected, since silver is a comparatively rare element, and, in the formation of sedimentary strata, would tend to become even more disseminated than in the original igneous masses. Even where found in sedimentary rocks, unless unquestionably bedded or segregated, the source may have been some deeper lying beds of igneous rocks. Silver is found, both in this and other countries, in mountainous regions, chiefly those of recent date, because here there are cavities for its deposition and abundant igneous rocks for a source of supply.

Uses of Silver. — Silver is extensively used in the arts, in jewelry, and in utensils, chiefly in tableware and show utensils. Its brightness and beautiful white colour make it valuable for these purposes, although its habit of tarnishing, when in the presence of sulphurous gases, detracts from its value. There are also numerous alloys of silver, the most important being an alloy of gold and silver, and copper and silver, the last two metals being added to coinage, and other gold, either singly or more rarely together, for the purpose of increasing its hardness. Coinage silver is alloyed with copper. By alloys of other metals crude imitations of silver are made. Such are the alloys of tin, nickel, and bismuth, of copper, nickel, tungsten, and aluminum, and of copper, nickel, zinc, and cadmium, etc., the latter bearing a closer resemblance to silver than the others.

Coinage has been an important use of the metal, but promises to become more and more unimportant. When, in 1873, the Latin Union and Germany and Holland ceased the free coinage of silver, this metal became a commodity, and since

then it has been subjected to the fluctuations in price which result from variations in supply and demand and the manipulation of syndicates; and this is probably the future fate of silver to even a more marked degree. From 1687 to the close of 1873 the ratio of silver to gold was remarkably uniform, having never fallen below 14.14, and in only two years having risen above 16.00. The general tendency, however, was toward a greater ratio of silver, or, what is the same thing, a smaller relative value. In 1687 the ratio was 14.94; in 1873 15.92; but since the latter year the ratio has steadily increased, until, in 1892, it reached 23.73, and is still (1893) increasing at a startling rate. Since 1859 the price of silver has decreased from \$1.360 to \$0.876 per ounce in 1892, with the price rapidly falling. This is due, not entirely to the suspension of free coinage, but, partly, to the increase in output. This increase began in 1860, but the price did not begin to fall rapidly until 1874. The coining value of silver in the United States is \$1.2929 per ounce, which is a highly artificial value.

If all the important nations of the world could agree upon a uniform ratio between gold and silver, the latter might still be safely coined; but such an agreement seems unlikely to be reached, and it is doubtful if, in the future, silver will be extensively used for coinage, excepting for small denominations. The future of the silver industry is therefore far from bright, and it will not be surprising if we should witness in the next few years a startling decrease in production. This metal has been given an unnatural position which it does not deserve. Grant it a permanent or moderately permanent value, something like its value in the middle of the last decade, and the output will continue to increase

even more rapidly than it has in the past; and there seems to be no moderate limit to the ultimate output. This metal, although truly a precious metal, and by no means common, is far too common for use as a standard of coinage, and its continued use for this purpose means a progressively increasing production which will call for a frequent re-establishment of the ratio. The nations which have not yet discovered this fact are liable to suffer for their shortness of vision.¹

For a verification of these remarks a comparative reference needs only to be made between the increase in output of gold and silver in the world during the past fifteen years. Between the years 1875 and 1891 the amount of silver annually produced in the world has increased from \$82,000,000 to \$185,599,600, while the increase in gold production has been from \$111,000,000 to \$125,299,700. These are startling and very significant figures when we consider the probability of a corresponding rate of increase for many years, provided free coinage is established without a marked increase in demand. In this country the relative increase in production of the two metals is even more striking; for, in 185' 1 part

¹ While this has been in the hands of the publishers, a long-continued and very varied discussion of the silver question has been in progress. All sides of the question have been considered, and finally the country has receded from its unfortunate position as a buyer of silver at an extremely artificial price. Much pressure has been brought to bear to prevent the repeal of the silver law, and much hardship has resulted in the mining districts. This has been, in part, at least, caused by the silver miners, who have in many cases closed mines which could readily be made to yield profit at a much lower price for silver than that now existing. The industry is very much depressed as the result of this interference with the unnatural stimulation of the past few years. A more helpful condition will, however, eventually follow this change, and the silver industry will become a more permanent and business-like industry.

of gold was produced to 0.016 of silver, and, in 1889, the product ratio was 1 of gold to 32.32 of silver.

The amount of silver coined in the United States from 1793 to 1824 exceeded \$1,000,000 in only two years. From that time to 1874 the coinage of silver fluctuated greatly, at one time (1853) reaching over \$9,000,000, and in 1864 falling to a little over a half million, while, in several other years the coinage fell below \$1,000,000. Since 1874 the coinage of silver has averaged nearly \$30,000,000 a year, and in 1890 reached \$39,202,908. During the year 1891 the silver coinage of the principal nations using this metal was as follows: India, \$32,670,498; United States, \$27,518,857; Mexico, \$24,493,071; Spain, \$11,251,000; Japan, \$8,523,904; Portugal, \$7,277,040; Great Britain, \$5,141,594. No other nation issued more than \$4,000,000 of silver.

Production of Silver. — The following tables show the value of the production of silver, in the United States and the world, based upon the United States coinage value, \$1.2929 per ounce.

PRODUCTION OF SILVER IN THE UNITED STATES.

STATES.	1877.	1880.	1885.	1888.	1890.	1891.
Colorado . .	\$4,500,000	\$17,000,000	\$15,800,000	\$19,000,000	\$21,307,070	\$27,358,384
Montana . .	750,000	2,500,000	10,060,000	17,000,000	20,363,636	21,139,391
Utah . . .	5,075,000	4,740,000	6,750,000	7,000,000	10,343,434	11,313,131
Idaho . . .	250,000	450,000	3,500,000	3,000,000	4,783,838	5,216,970
Nevada . . .	26,000,000	10,900,000	6,000,000	7,000,000	5,753,535	4,551,111
Arizona . . .	500,000	2,000,000	3,800,000	3,000,000	1,292,929	1,913,535
New Mexico .	500,000	425,000	3,000,000	1,200,000	1,680,808	1,713,131
California . .	1,000,000	1,100,000	2,500,000	1,400,000	1,163,636	969,697

Nearly one-half of this product comes from silver-lead ore. Over one-third of the total amount of silver produced in the United States comes from Colorado, nearly two-thirds from Colorado and Montana, and practically all from, or west of, the Rockies. In 1891 the only other states producing over \$100,000 of silver, and all of these less than \$500,000, are, in the order of their rank, Texas, Oregon, Washington, and South Dakota.

Colorado increased its output at a remarkable rate from 1877 to 1880, owing to the development of the Leadville mines, and since then the production has steadily increased. In 1880 this state took the lead from Nevada, and this it has maintained each year, with the exception of 1887, when Montana produced a little more than Colorado. The output of silver from Montana has increased rapidly, and both Utah and Idaho have slowly increased. Nevada, on the other hand, has decreased its output very greatly, chiefly because of the abandonment of the Comstock Lode.

SILVER PRODUCTION OF THE UNITED STATES.

1857	\$50,000
1861	2,000,000
1864	11,000,000
1869	12,000,000
1871	23,000,000
1874	37,300,000
1880	39,200,000
1885	51,600,000
1890	70,465,000
1891	75,416,500
1892	83,909,210

There has been a steady and very rapid increase, with some fluctuations, since 1861. From 1880 to 1892, inclusive, a period of thirteen years, there has been an average annual increase of nearly \$3,440,000, and, in the last few years, a much greater rate of increase.

PRODUCTION OF SILVER IN THE WORLD.

COUNTRIES.	1880.	1885.	1888.	1890.	1891.
United States. . .	\$39,200,000	\$51,600,000	\$59,195,000	\$70,465,000	\$75,416,500
Mexico.	25,167,763	32,112,000	41,373,000	50,356,000	53,000,000
Bolivia.	11,000,000	10,000,000	9,578,000	12,514,200	15,488,000
Australasia. . . .	227,125	1,048,000	5,000,000	10,731,300	12,929,300
Germany.	5,576,699	1,021,000	1,332,022	7,567,500	7,480,800
Peru. . . . .	..	1,988,000	3,128,000	2,734,300	3,112,000
Chili.	5,081,747	8,727,600	7,723,957	5,140,800	3,000,000
France. . . . .	..	2,120,000	2,053,000	2,955,600	2,955,600
Spain.	8,096,220	2,258,000	2,140,400	2,140,400	2,140,400
Austria-Hungary	1,994,880	2,192,200	2,166,440	2,103,500	2,103,500
Central America	....	....	2,000,000	2,000,000	2,000,000
Japan.	916,400	960,000	..	1,765,000	1,708,800
Columbia.	1,000,000	400,000	1,000,000	830,000	1,298,000
Total for World	\$96,700,000	\$118,095,150	\$140,706,413	\$173,743,000	\$185,599,600

The United States, in 1891, produced 40.6 per cent of the silver of the world; Mexico 28.5 per cent, and these two countries together 69.1 per cent of the world's supply. The United States, Mexico, Bolivia, and Australasia produced 84.5 per cent of the silver, and over three-fourths of the supply of the world came from the western hemisphere. In the above table the most striking facts are the steady increase of ^{the} output from the important silver-producing countries and the remarkably rapid rate of increase in the case of the United States, Mexico, and Australasia.

SILVER PRODUCTION OF THE WORLD.

1849	\$39,000,000
1860	40,800,000
1865	52,000,000
1870	64,000,000
1875	82,000,000
1880	96,700,000
1885	118,095,150
1890	173,743,000
1891	185,599,600

Between the years 1860–1891 inclusive, thirty-one years, the increase in production of silver has been at the rate of nearly \$1,700,000 a year. From 1872 to the close of 1891, twenty years, the annual rate of increase has exceeded \$5,700,000, and within the past few years this rate has been much greater, and at present is more than double the latter amount.

CHAPTER IX.

COPPER.

General Statement. — Copper, like silver, varies widely in mineralogical association and mode of occurrence. The ores most commonly found are, native copper, the sulphide chalcocite, the sulphides of copper and iron bornite and chalcopyrite, the oxides cuprite and melaconite, the silicate chrysocolla, and the carbonates azurite and malachite. Other ores are more rarely found, but the most important sources of copper are the sulphides and native copper, the other minerals being usually the result of oxidation above the water-line. Almost every mode of occurrence is illustrated by mines of this metal, and usually other metals are found in association with the copper. This is very markedly true in England, Germany, and Austria, where, from the same mine, gold, silver, copper, lead, zinc, and other metals are extracted. Indeed, aside from the mechanical association of the ores of these metals, the sulphides of copper are usually complex, and, by metallurgical processes, both gold and silver are frequently obtained from them. A not inconsiderable percentage of the supply of these two metals comes from this source, and, where the ores of copper are argentiferous or auriferous, the mining and extraction of copper is sometimes rendered profitable in places where, without the presence of precious metals, this would not be possible.

A very few countries supply the copper of the world, and if it were not for the mines of the United States, Spain, and Chili, the product of the world would be very limited. In the United States, which is far ahead of other nations in the production of this metal, as well as in that of silver and gold, the distribution of the ore is very local. Only three districts, Montana, Michigan, and Arizona, are of particular importance as copper-producers; and of these, the first two produce by far the greater amount. In these two states the copper comes from two exceedingly small areas.

Appalachian States. — From the eastern and southern states only a few hundred tons (in 1892, 580 tons) are annually produced. There are, however, in this belt, chiefly in the metamorphic rocks, considerable stores of medium and low grade copper pyrite which have, in the past, given to the states of this region an importance in the production of copper far greater than they now possess. The development of the copper mines of the west caused these to be discontinued, because of the fall in price of the metal; but now that the demand for copper continues to increase, and new methods of cheap mining and extraction have been perfected, the future of this district seems brighter. In several of these states small copper mines are being exploited, but Vermont is the most important of them all. Here from the Copperfield mine 1,200,000 pounds were produced in 1892. The copper mines of the belt of metamorphic rocks are, in some cases, in segregation veins; in others, in fissure veins; and of the former class there are many veins which are either too small or too uncertain for exploitation, while others are merely copper-bearing iron pyrite veins. With the conditions

existing in Germany and Austria, this district would assume considerable importance in the production of copper and other metals.

Lake Superior District. — In copper, as in iron production, Michigan assumes importance, and in the case of both of these metals, the productive area is the belt of older rocks on the peninsula between Lake Superior and Michigan. This district, though now of second rank in this country, has, since its opening, produced more copper than any other in the world. Already the largest of the mines, the Calumet and Hecla, has extended to a depth greater than 4000 feet below the surface, and there appears to be no sign of a decrease in supply. There are here a number of mines, great and small, some of them producing only a few thousand pounds of copper a year, but nine of which annually produce more than a million pounds, while the greatest, the Calumet and Hecla, had an output in 1891 of more than 63,000,000 pounds. A number of the smaller mines have recently ceased operations, but the larger ones either maintain or increase their output from year to year. If necessary, the production of this district could be vastly increased for some time to come.

The mines of the Keweenaw Point district were first discovered in 1845, although for centuries before this the Indians had made use of the boulders of copper for implements and ornaments. Since 1845 the output from the Lake Superior region has steadily increased, with some minor fluctuations of recent date. In some of the mines, mineralized ores of copper are the source of the metal, but the most common ore is native copper frequently associated with native silver.

A series of interstratified sandstones, conglomerates, and diabases, of Algonkian age, form the rocks of the region, and these are tilted at an angle varying from 30° to 60° . The diabases are usually very much altered, and are classed as melaphyres; and that they are actual lava flows buried beneath later sediments is shown by a study of their field relations, and by the fact that many of them are amygdaloidal.¹ Copper occurs in these rocks in several conditions. The most important source of the metal is from the sandstones and conglomerates where it occurs as a cement, in grains, ramifying masses, and bunches sometimes weighing many tons. Usually the native copper ramifies through the rock, in the interstices between the pebbles and grains of sand, cementing them together, and frequently entering the crevices in the pebbles themselves. For the extraction of the metal the rock is crushed and then separated by concentrators. Strange though it may seem, the large masses of copper, which are too heavy for removal, are usually of little value, since they cannot be picked, nor blasted, nor cut excepting with great difficulty by means of chisels.

A second source of copper is from the trap or melaphyre, where it is found, also in a native state, as a partial or complete filling of the amygdaloidal cavities, usually in association with calcite, quartz, native silver, and numerous other minerals. Native copper also occurs at the contact of the diabase flows, in veins of secondary minerals, chiefly epidote, and also in true fissure veins with calcite and quartz gangue. Here the influence of the country rock is well shown by

¹ An amygdule is a cavity in an igneous rock caused by the expansion of gas, usually aqueous vapour, and either partly or completely filled by the percolation of water at some subsequent time with a foreign mineral.

the fact that these latter veins are frequently unproductive in the sandstone and conglomerate, although often rich in both silver and copper in the trap.

The origin of this remarkable deposit has been variously accounted for by the different students of the geology of that region. That it is not a true contact deposit is shown by the fact that the amygdules in the diabase, the fissure veins, and the crevices in the broken pebbles are filled with copper, showing a subsequent deposition. In the igneous rocks copper is, next to iron, the most common of the metals which are used extensively in the arts; and in none of these rocks is it more common than in diabase. A long-continued process of alteration has been passed through by the diabase, and the result is that many of the original minerals have been entirely changed in character. Probably, during this change the metallic constituents, together with quartz and calcite, were removed from the diabase and deposited in their present position.

Whether by the decay of the heavy bisilicates, native copper was originally set free, or whether it was in the form of a sulphide in the rock, is a question which may not unreasonably be answered by assuming that both conditions were present, since diabases contain free sulphides of copper and also copper associated with the bisilicates. In order to explain the supposed alteration from copper pyrite to native copper, electro-chemical changes have been suggested, and this is a very reasonable hypothesis. The occurrence here is analogous to what is happening in many rocks, excepting that, in this case, we are dealing with copper instead of some more abundant substance. There are few more common phenomena in geology than the cementing

of sandstones and conglomerates by oxide of iron, calcite, or quartz; and amygdaloidal cavities filled with these or other minerals are present in all porous lavas which have been buried for a sufficient length of time to come under the influence of percolating waters.

From 1847, when Michigan produced 213 tons¹ and the entire country 300 tons, to 1881, when Michigan produced 24,132 tons of the total output of 32,000 for the country, this state was the great copper-producer of the Union. Since 1853 the output has exceeded 1000 tons, and has gradually and steadily increased, and since 1870 more than one-half of this supply came from a single mine, the Calumet and Hecla. Next to this mine the Tamarack and the Quincy are the most important in the district. The following table shows the increase in development of this region as a whole, and of these three mines, since 1860. Neither of these two mines produced copper in 1855, and the output of the district in that year was only 5,932,170 pounds.

PRODUCTION OF COPPER IN THE LAKE SUPERIOR DISTRICT.
POUNDS.

	CALUMET AND HECLA.	TAMARACK.	QUINCY.	TOTAL LAKE SUPERIOR MINES.
1860	....	....	1,940,414	12,301,538
1870	14,061,584	....	2,572,980	24,290,231
1875	21,473,954	....	2,892,617	36,097,898
1880	31,675,239	....	3,696,263	49,615,811
1885	47,247,990	181,669	5,848,530	72,759,082
1890	59,868,706	10,106,741	8,064,253	100,695,359
1891	63,586,620	16,161,312	10,542,519	114,328,218
1892	57,925,000	16,426,683	11,103,926	107,540,304

¹ Long tons of 2240 pounds are used for the United States.

Montana Mines.—Twelve years ago Montana produced practically no copper, whereas now this state is far ahead of all others in the production of this metal. Very nearly the entire output of the state comes from a hill in the town of Butte, which is now the largest mining camp in the world. In this district there are a large number of claims, but few important mines. The ores are copper sulphide and chalcopyrite, with some blende and galena, in a gangue of quartz. Nearly all of these ores carry silver. The hill at Butte is a granite knob, crossed by rhyolite dikes which are a possible source of the copper. A series of nearly parallel veins cross the granite in fissures which extend beyond the limits of the hill. There is a considerable variation in the character of the ore in different veins, and even in the same vein; but, although the Anaconda mine has reached a depth of considerably more than 1000 feet, there are no signs of exhaustion. The walls of the veins are not distinct, but they have been partly replaced, and the veins enlarged by impregnation deposits.

Notwithstanding numerous accidents, these mines have increased their output at a remarkable rate, and at present they produce more ore than any other copper district in the world. They are now producing fully 3000 tons daily, and it is claimed that the output can be easily made to reach 175,000,000 pounds a year. The following table shows the wonderful development of the copper industry in Montana since 1882:—

PRODUCTION OF COPPER IN MONTANA.

1882	9,058,284 lbs.
1883	24,664,346 "
1884	43,098,054 "
1885	67,797,864 "
1886	57,611,621 "
1887	78,699,677 "
1888	97,897,968 "
1889	98,222,444 "
1890	112,980,896 "
1891	113,200,000 "
1892	164,300,000 "

Thus, in 1892, the output was increased over 51,000,000 pounds, chiefly as the result of an increase in activity in the Anaconda mine.

Arizona and other Western Mines.—Arizona has for many years been an important copper-producing territory, having, in 1882, held second rank, and since then third rank, in the country. Almost all of the ores at present mined are oxidized; and although there are great stores of copper here, the mines are not being rapidly developed, and the output is not increasing at a rate comparable with that of the two leading copper-producing states. There are several districts, and in all, so far as is known to the author, they are associated with eruptive rocks. We have not, however, as complete descriptions of these mines as of the two just described. As instances of the modes of occurrence of copper in Arizona, mention may be made of three mines: the Coronado, where the ore occurs in a dike of quartz porphyry crossing granite; the Longfellow mine, in the Clifton district, in which the ore occurs in veins near the contact of felsite and

limestone; and the Black copper mine of the Globe district, where the ore is found in stockwerks, in gneiss, near a mass of diorite. The most important copper mines of the territory are the Copper Queen, United Verde, Old Dominion, and the Arizona Copper; but there are numerous other mines of less importance.

Colorado, which is next in order of importance, has no large copper mines, but a number of small deposits are being worked, and considerable is supplied from the mines of other metals, notably from the Leadville lode, which is becoming richer in copper and poorer in other metals as the depth increases. The output from this state has shown a considerable increase in the last ten years. In California very nearly the same conditions occur; but, owing to a fire in the principal mine, there was a slight decrease in output in 1891. More than one-half of the copper of Utah comes from a single mine, and the remainder chiefly from copper-bearing argentiferous galena. Valuable deposits exist in New Mexico, but the output of this territory has, so far, been very slight.

Foreign Copper Mines. — The copper district of Spain and Portugal is next in importance to the United States. A copper-bearing series extends from near Seville across the Portuguese line to the Mason and Barry mine. The mines are situated in a zone of nearly vertical clay slates, with quartz porphyry dikes near by and nearly parallel to the veins. Being lenticular and parallel to the cleavage of the slate, the veins appear to be of segregation origin; but whether the ore has been derived from the slate or the igneous rock has not been determined. Chalcopyrite, usually argentiferous, is the principal ore, but the black sulphide of copper is

also present. These veins were worked by the Romans, and the timbers used by them in their irregular galleries are admirably preserved by the presence of the salts of copper. From the very earliest times these mines have been worked as pits as well as true mines, and this is still the case. The Rio Tinto mine is by far the most important, and this at present has large quantities of copper in sight; but the Tharsis in Spain and the Mason and Barry mines across the Portuguese line are both very productive. Spain promises to keep the lead as a copper-producing country among European nations for a long period.

Chili has an output of copper of greater value than that of any other mineral product, but the industry is declining. In 1855 this country produced one-half of the copper of the world, but to-day it produces less than one-tenth, this result being in large measure due to the increased production of other nations. There is, however, a noticeable decrease in the output of copper from Chili, and this is due in part to the decrease in richness of the ore in the lower tunnels of the mines and the increase in cost of mining at these depths, and partly to the unscientific methods of reduction by which the gold and silver contents are lost. The ores are copper pyrite below the water line and carbonates, silicates, etc., nearer the surface. Here, as in nearly all copper mines, there is an association with igneous rocks; in the Rosario mine with diorite, in the Panulcillo as an apparent contact vein between mica schist and porphyry, and in the Carrizal Alto a vein frequently crossed by dikes and increasing in richness near these intersections. Other South American countries are not important as copper-producers. Venezuela ranks next to Chili, the principal mine

there being the Aroa. Neither Bolivia nor Peru have assumed any considerable importance in this industry, although in both countries there are extensive deposits, at present inaccessible because of lack of transportation facilities.

In Japan copper has been produced for over twelve centuries, and at present this country is the fourth most important. For 250 years the output of these mines has averaged nearly 3000 tons annually. Of the Japanese mines, the Ashio vein is by far the most valuable. The ore is black copper occurring in a fissure vein associated with eruptive rocks. Other Asiatic countries are not important copper-producers.

Next in importance to Japan is Germany, which is second in rank among European countries. A small portion of the output comes from the various silver lead mines, such as Clausthal, the Freiberg mines, etc. In the Andraesberg district, copper is obtained from veins in clay slate of Silurian age near a granite mass. But nearly ninety per cent of the German copper comes from Mansfeld, at the southeastern end of the Harz. Here a series of folded sandstones, conglomerates, gypsum beds, and bituminous marls occur, the latter being copper-bearing, and resting upon the sandstones and conglomerates as a bedded deposit. The copper-bearing shale in this marl contains from two to five per cent of copper in the form of grains of silver-bearing copper pyrite. Other ores are found, but not in abundance, and the copper itself, although occurring throughout the shale, is present in workable quantities in only a few bands. This very interesting deposit is rendered unworkable at the lower depths because of the influx of salt water from a salt lake, the Salziger See, from which water enters the mine faster than it can be pumped out. The future of the mine is seriously

threatened by this difficulty, and the only possible relief is to drain the lake.

Russia ranks next to Germany among European nations as a copper-producing country. There are several districts, one in the Permian and Triassic strata on the western slope of the Urals, and another in the district of Nijne-Taguilsk in metamorphic schists not far from a mass of diorite. From both of these districts malachite and azurite are obtained in masses of sufficient size for ornamental work. This is particularly true of the latter region, which supplies the greater part of these minerals. That they are merely oxidized ores is proved by the fact that they pass into sulphides as the dept. of the mines increases.

Copper, in the form of copper pyrite, is found in Italy in chlorite schists associated with granites, and also in other districts usually in association with igneous rocks. Some of these mines were worked by the Etruscans. In Norway and Sweden this metal, chiefly in the form of pyrite, occurs in the metamorphic rocks. The Stora Kopparberget mine of Sweden has been worked since 1228 and perhaps earlier, and, although at the present only 271 tons are annually produced, this mine had an output in the seventeenth century varying between 2000 and 3000 tons. In Austria the copper is mined chiefly as an accessory in the silver lead mines, and the output is exceedingly small. The same is true of England, which every year becomes less important as a copper district, the chief supply coming from Devonshire and Cornwall.

The various colonies of Australasia produce copper, and the output of these countries combined give to this general area a rank next to Germany. Africa also produces some

copper, the most important district being Cape Colony. Mexico, next to Australasia in importance, has produced very little from mines other than the Boleo mine of Lower California, where there is a very large deposit, which is profitably worked even with the difficulty of obtaining labour in that sparsely settled peninsula. Canada has copper mines in the metamorphic rocks of the province of Quebec, in Nova Scotia, and elsewhere, and recently important discoveries have been announced in British Columbia. The Algoma nickel mines are important sources of Canadian copper. From the metamorphic rocks of Tilt Cove, Little Bay, and elsewhere in Newfoundland, copper pyrite has been produced in considerable quantities. Recently the industry has rapidly declined, and at present some of the most important mines are closed. There are other valuable deposits in different parts of the island, but the poverty of the colonists, the inaccessibility of the region, and the existence of certain fishing privileges which the French hold, have interfered with their development.

Occurrence and Origin of Copper. — The distribution of copper deposits is extremely widespread, but the greater part of the world's supply comes from a very few localities. Excluding the mines at Keweenaw Point (Michigan), Butte (Montana), one or two mines in Chili, the Ashio mine of Japan, the Rio Tinto series in the Spain-Portugal region, and the Mansfield mines of Germany, and the copper product of the world is extremely slight. Yet these important areas cover only a few hundred square miles. Africa, outside of Cape Colony, Asia, exclusive of Japan, and South America, with the exception of Chili, are practically non-producers of copper. But in all of these regions copper is found, and if

the demand continues to increase, and facilities for transportation are introduced, some of these will be developed, particularly if, as seems possible, the present extravagant production of the large mines of this country continues until they are exhausted. The American mines have had a disturbing influence on the copper market of the world, and have made copper mining impossible in some districts; but, on the other hand, they have been the means of introducing new and more economical methods of extraction, and, at the same time, by reducing the price, have aided in the introduction of copper into new fields.

It will be noticed, in the above description of the copper occurrences of the world, that the Lake Superior mines are practically unique in the fact that they are deposits of native copper. Elsewhere the predominating ore is chalcopyrite, and, to a less extent other sulphides, below the water line, but above this carbonates and silicates predominate. As to the mode of occurrence, copper is found in segregated veins in the metamorphic rocks, in fissure veins and contact deposits principally in other rocks, and also, in some cases, in the metamorphics. There is an almost universal association with igneous rocks, and, in some cases, this can be shown to be due to the presence of the igneous rocks, while, in other instances, this relation seems probable. While this association is at times a true contact effect, it is generally the result of a secondary process of concentration. Usually the copper is associated with other sulphides, chiefly blende and galena, and very commonly it is argentiferous and auriferous. This association with other metals is particularly common in the fissure veins, and sometimes one, so. etimes another, of the sulphides predominates.

While in most cases the ores of copper are associated with igneous rocks, this is not invariably the case, as, for instance, in the Mansfield mines of Germany. In such places the ore may have been precipitated from a copper solution when the strata were deposited, and subsequently concentrated; or it may have been concentrated from some extraneous sedimentary source, as is so commonly the case in iron ore beds. Analyses show copper in igneous, sedimentary, and metamorphic rocks, and in some cases its presence can be detected with the eye. Therefore, any of these rocks may serve as a source of copper, although its predominance in igneous rocks and their greater liability to decay and alteration, with the consequent formation of various soluble salts, make these the most common source.

Uses of Copper.—Since prehistoric times copper alloyed with tin has been used in various parts of the world for the manufacture of bronze. Thus it was used for this purpose in Homeric times, and it is found in the lake dwellings of Switzerland. The bronze found in Troy contains very little tin, and since this metal is not found in the excavations in the west, it seems probable that the bronze was made in Asia, perhaps in China or India, by some secret process and imported to the western countries.

By an alloy of copper and tin, although both metals are soft, a comparatively hard metal is produced. The properties of this alloy, bronze, vary greatly according to the proportions of the two metallic constituents, and these vary with the use for which the alloy is intended. United States ordnance is 90 per cent copper to 10 per cent of tin, and ordinary bell metal is about 80 per cent copper, though the percentage varies with the tone required. Statuary bronze is generally an alloy of

copper, tin, and zinc ; and, in these various bronzes, the colour varies from copper-red to tin-white, passing through an orange-yellow. A bronze containing two per cent of phosphorus makes a metal which is claimed to be equal to the best steel. There are many hundred different kinds of bronze, and every year many patents are granted for new bronzes.

An alloy of copper and zinc produces brass, which is found of so much value for small articles used in building and for ornamental purposes in machinery. Copper is also used in roofing and plumbing, and at one time an extremely important use was for sheathing vessels below the water line. This is still in use, by some vessels, but the demand for copper for this purpose is distinctly decreased by the introduction of iron vessels and by the substitution of a copper paint.

A large supply of this metal is made into copper wire ; but the most important present use of copper is in electricity, for which its high conductivity especially fits it for the conduction of electric currents. With the introduction of electricity into nearly every industry, and particularly by its widespread adaptation to lighting and transportation, the demand for copper has increased at a marvellous rate in the last ten years, a rate which has been attained by no other single use of any metal. Whether the demand will continue at the same rate, and if so, whether the supply will correspondingly increase, are questions of great interest which will probably be answered in the affirmative. The continued rapid extension of electricity seems certain, and the supply of copper is apparently unlimited, yet it is a question whether it is expedient for our great mines to exhaust their supplies, for the benefit of a foreign market, at a low price, while there is a danger that in the future we may need the supplies ourselves.

The price of copper (Lake Superior copper) has varied greatly since 1860, when it averaged $22\frac{1}{4}$ cents per pound. During 1864 it averaged $46\frac{1}{4}$ cents, and in July of that year was sold at $59\frac{3}{4}$ cents. There was, however, a gradual though fluctuating decline to 1886, when the price reached 11 cents. In 1888 the price reached $17\frac{1}{4}$ cents, but fell again in 18 '9, then rose, and during 1892 the average price was $11\frac{1}{2}$ cents per pound. The fluctuations, in the period immediately succeeding 1887, were due to the manipulation of a French syndicate. Now, owing to an understanding between the leading copper-producers of the world, which limits the production and exportation, a moderately uniform price is assured.

The United States consumed, in 1860, 14,232,000 pounds of copper; in 1870, 24,684,000 pounds; in 1880, 53,598,000 pounds; in 1890, 190,541,676 pounds; and in 1892, 266,895,715 pounds, this recent immense increase being chiefly due to the demands of electricity.

Production of Copper. — The following tables illustrate the distribution of the copper output of the world: —

PRODUCTION OF COPPER IN THE UNITED STATES.
POUNDS.

STATES.	1882.	1885.	1888.	1890.	1892.
Montana . . .	9,053,000	67,797,864	98,504,000	110,996,000	164,300,000
Michigan . . .	57,181,000	72,759,000	86,503,000	100,695,000	107,300,000
Arizona . . .	17,934,000	22,706,366	33,200,000	34,900,000	38,000,000
Colorado . . .	1,494,000	1,146,000	1,621,000	6,000,000	7,250,000
California . . .	827,000	469,000	1,570,000	1,600,000	3,200,000
Utah	646,000	126,000	2,131,000	600,000	2,000,000
New Mexico . .	869,000	80,000	1,631,000	870,000	500,000
Total for the } United States }	90,794,000	166,486,230	228,501,000	259,561,000	325,180,000

Of the Montana supply in 1892, 100,000,000 pounds came from a single mine, the Anaconda, and more than 30,000,000 from the Boston and Montana. In 1891 Michigan produced over 1,000,000 pounds more copper than Montana, but since 1887, with this exception, Montana has produced more than Michigan. Since the beginning of 1883 Arizona has held third place, although its output has steadily increased. In 1890 Maine, New Hampshire, and Vermont produced together 378,840 pounds of copper, and in 1892, outside of the states and territories in the above table, only 2,500,000 pounds were produced in the country.

COPPER PRODUCTION OF THE UNITED STATES.

LONG TONS (2240 LBS.).

YEAR.	AMOUNT.	VALUE.
1846	150	....
1850	650	...
1860	7,200	...
1870	12,600	...
1880	27,000	\$11,491,200
1885	74,324	18,292,999
1890	116,009	30,930,800
1892	145,170	37,850,000

In 1846 the Lake Superior mines produced 26 per cent of the copper of the country ; in 1870, 87.2 per cent ; and since this time the percentage has rapidly decreased, until in 1891 only 40.2 per cent of the output of the country came from this district, while in 1892 the percentage was much smaller. During the year 1892 the United States imported copper to the value of \$730,384, while it exported \$10,162,870 worth of this metal. The imports, which come mainly from Canada and Spain, are chiefly ores which are melted in the United States. Our supply therefore greatly exceeds our needs.

COPPER PRODUCTION IN THE WORLD.

LONG TONS (2240 LBS.).

COUNTRIES.	1879.	1883.	1887.	1890.	1892.
United States . . .	23,350	51,570	79,109	116,009	145,170
Spain and Portugal .	33,361	44,607	53,706	51,700	46,600
Chili	49,318	41,099	29,150	26,120	20,000
Japan	3,900	7,600	11,000	15,000	18,000
Germany	9,000	14,643	14,875	17,800	16,687
Australia	9,500	12,000	7,700	7,500	7,700
Mexico	400	489	2,050	4,325	7,603
Africa	4,328	5,000	7,250	6,450	6,728
Russia	3,300	4,400	5,000	4,800	5,000
Venezuela	1,597	4,018	2,900	5,640	3,021
Total for World .	151,963	199,406	223,798	269,615	291,474

The noteworthy features of this table are the remarkable increase of the production in the United States, the steady increase of the Japanese output, the increase in Mexico, since the opening of the Boleo mine in 1887, and the steady decline of the Chilean copper production.

COPPER PRODUCTION BY CONTINENTS.

LONG TONS (2240 LBS.).

CONTINENTS.	1884.	1886.	1889.	1891.
North America. .	63,903	73,845	110,134	137,864
Europe	75,224	75,203	84,843	81,210
South America. .	48,269	40,088	31,983	29,015
Asia	10,000	10,000	15,000	17,000
Africa	5,260	6,125	7,860	6,020
Australasia . . .	14,000	9,700	8,300	7,500
Total	218,756	214,961	258,120	278,609

The African supply comes from Cape of Good Hope, the Asiatic from Japan, the European chiefly from Spain, Portugal, and Germany, the South American mainly from Chili and Venezuela, and the North American almost entirely from the United States.

COPPER PRODUCTION OF THE WORLD.

LONG TONS (2240 LBS.).

1879	151,963
1881	163,369
1885	225,592
1888	258,026
1890	269,615
1892	291,474

It is a remarkable increase in the production of an important metal, which nearly doubles the output in fourteen years, and this could be made possible only by a marked increase in the uses of the metal. It is a striking fact in this connection that the price has fallen in this period less than 6 cents, or from an average of $17\frac{1}{3}$ cents for the year 1879 to $11\frac{1}{2}$ cents in 1892. Of the total output of 291,474 tons in 1892, the United States supplied nearly one-half.

CHAPTER X.

LEAD AND ZINC.

Lead.

General Statement. — The ores of lead and zinc are almost inseparably associated; for, with very few exceptions, the mines of the one contain the other, although usually one of the two predominates. The metals are, however, considered separately in this case. There are two general sources of lead, the argentiferous and the non-argentiferous galena, the latter being found usually in association with zinc blende, and both of these lead ores being weathered near the surface to the carbonate cerussite, the sulphate anglesite, etc. Where the ore is argentiferous, it is generally found in fissure veins or near some eruptive rock, but the non-argentiferous galena occurs commonly in stratified rocks.

As in the case of gold, silver, and copper, the principal source of this metal is the Cordilleras, but the states of the Mississippi valley are also important producers. In the former region the ore is chiefly silver and gold bearing, in the latter it is non-argentiferous and is associated with zinc. Were it not for the presence of the precious metals in much of the Cordilleran galena, it is doubtful if the output from these states would be so great. Non-argentiferous galena can be profitably obtained only where it is easily mined or where it exists in considerable quantities.

Appalachian District.—From Maine to Georgia galena occurs in the metamorphic rocks; and at numerous points in this belt mines have been opened in these veins. Some of these have been exploited for many years, and even made to produce fair returns, but very few are open at present. The ore occurs generally in small veins, sometimes segregated, but it is usually not sufficiently argentiferous nor extensive enough to make mining profitable. Moreover, the veins are not always permanent, and they usually become poorer as the depth increases. This region never will become important in the production of lead, but it may, in time, become of more importance than it is at present.

Missouri Lead District.—In various parts of Missouri, Kansas, Wisconsin, Illinois, and other neighbouring states,

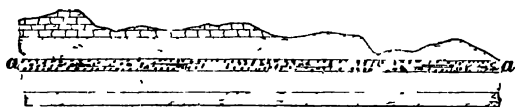


FIG. 20.—Ideal section showing mode of occurrence of lead in Wisconsin.
a, a, lead-bearing stratum.

lead and zinc are found, free from association with the precious metals, in the ores galena and blende. The region is one of slightly disturbed sedimentary rocks, of an age varying from Cambrian to Carboniferous. Certain strata of limestone, of a dolomitic character, are ore-bearing, those in the upper part of the region being the Galena limestone of Lower Silurian age, and in the lower part strata of the Keokuk group of the Lower Carboniferous. When the Mississippi valley was first explored, lead was found in boulders on the surface, and this added zest to the early explorations for the precious metals, which, however, were never found

in this region. The early settlers in the valley found this lead of great value in the manufacture of shot and bullets, since the transportation of this heavy metal, from the sea-shore through the wilderness, was a very difficult task. At first the lead was smelted by very primitive methods and moulded into the required form, but before the beginning of the present century, a shot tower was erected there. Actual

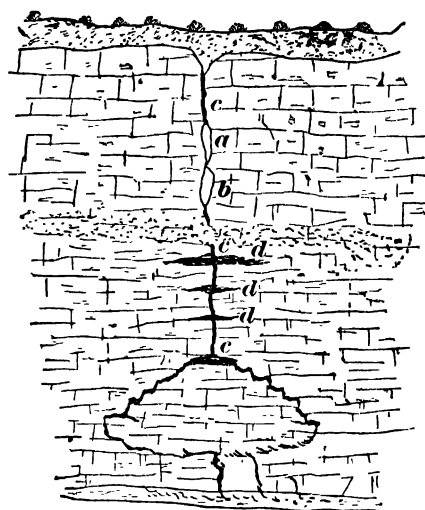


FIG. 21. — Ideal section showing forms of "openings" and ore deposits in the Galena limestone, Wisconsin. *a*, vertical crevice opening; *b*, cave opening; *c*, gash vein; *d, d, d*, flat openings. (After Chamberlain.)

mining was first begun near St. Louis, but it was not long before mining operations were extended into the neighbouring states.

The ore occurs in the nearly horizontal limestones in flat openings parallel with the bedding, in gash veins of variable size at right angles to this, and in caves in the limestone. Fossils are not uncommonly found replaced by galena or

blende, and in the caves actual stalactites of galena occur. These facts show that the ore has been gathered together since the formation of the limestone; and as it is confined to single strata over wide areas, it is certain that its origin is either from the ore-bearing stratum or from the strata immediately above or below, probably the former.¹

As we proceed in the study of lead-zinc deposits, it will be found that this is a common mode of occurrence in various

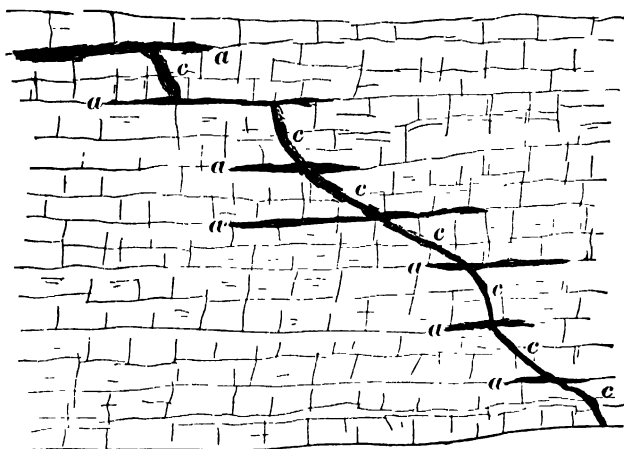


FIG. 22. — Section showing flats (a) and pitches (c) in Galena limestone, Wisconsin. (Modified from Chamberlain.)

parts of the world, and it must be granted that, in certain limestones, usually dolomitic limestones, there was a store of disseminated zinc and lead, which, under favourable circumstances, was accumulated into these deposits. Sea-water contains these metals, and they may have been precipitated from solution, or certain animals may have extracted them

¹ Recent studies show that there are small fissures connected with these deposits and that they have in part influenced the ore accumulations; but this does not essentially modify the above conclusions.

from the water and built them into their calcareous skeletons. A plausible and rather attractive theory is that the source is from sea-weeds, which at present are known to contain these metals. This theory assumes that in the sea, over the point where the ore-bearing limestone was being deposited,

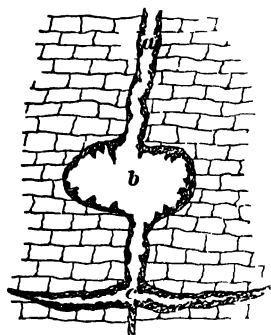


FIG. 23.—Section showing gash vein (*a*), cave opening (*b*), and flat opening (*c*), in the Galena limestone. (Modified from Chamberlain.)

a Sargassum sea existed, as is the case in the central North Atlantic and other oceans, in the swirl enclosed by oceanic currents. The Mississippi valley, in the Palæozoic, was occupied by a great ocean bounded by land areas on the north, east, and west, and such a condition may well have existed there. If such an accumulation of sea-weed did exist in this region, the constant decay of the vegetation might have furnished to the

ocean bottom a supply of both these metals, but it must be admitted that this is merely hypothesis. The facts are that in some way zinc and lead were incorporated into these strata, and later segregated, but by just what means we cannot say.

Even from the very first, these deposits have been worked by individuals or small companies as superficial open-work mines. The conditions do not favour the formation of large companies, because the mining operations are simple, very little machinery is called for, drainage is easily obtained, and no deep or extensive tunnels and shafts are needed. Moreover, the ore is found in irregular accumulations, sometimes yielding large returns, but often being absent. These conditions have led to the general adoption of this system, each

land-owner working his own area or leasing it to others on shares. Recently, however, the mining operations have been extended by the discovery of the ore, in borings, at considerable depths, and even beyond the limits of the original lead-producing belt. By these means the district is becoming more productive.

Colorado Lead Mines.—The Leadville silver-lead vein, in the Mosquito Range, at the head-waters of the Arkansas River, has been one of the remarkable lodes of the country; and this gave to Colorado its first important start as a mining state. From an area of about a square mile the output of silver has been, for a number of years, greater than that of any foreign country, with the exception of Mexico. During the same period the production of lead has been nearly equal to that of England, and greater than any other European country excepting Spain and Germany. In 1860 a placer deposit of stream-gold was found, in a gulch near this lode, and several million dollars' worth of this metal was extracted, causing the establishment of a flourishing town called Oro, which, however, soon lost its importance when the gold began to be exhausted. Not until 1875 was the carbonate of lead, which has since been so important, actually recognized.

There are several modes of occurrence in this vein; but the typical one (Fig. 24) is between a bed of blue-gray dolomitic limestone of Lower Carboniferous age, for a foot wall, and a sheet of porphyry for the hanging wall, the dip being extremely variable, from steep to very gentle. The upper wall is sharp and distinct, but the ore passes by gradual transition into the underlying limestone. Argentiferous galena, bearing native gold, is the actual ore, but above the

water line this is weathered to the carbonate and sulphate. The gangue is limestone, barite, and chert, with ores of antimony, molybdenum, copper, bismuth, zinc, etc. Through this the ore is distributed irregularly, the lead ore being chiefly in the limestone, the copper and gold in and near the eruptives and crystallines. Mr. Emmons,¹ who has studied this vein, has arrived at the conclusion that the ore was deposited in the form of sulphides in the overlying quartz porphyry,

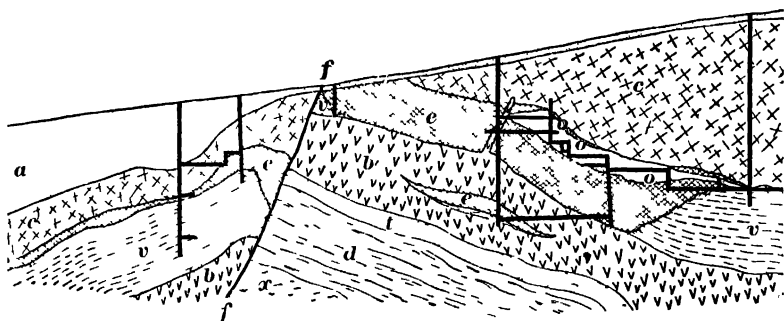


FIG. 24.—Cross section of Evening Star Mine, Carbonate Hill, Leadville, Colorado. *a*, recent deposits, *b*, porphyry, *c*, white porphyry, *d*, white limestone, *e*, vein material in blue limestone stratum, *f*, fault, *g*, ore, *h*, quartzite, *i*, blue limestone, *x*, lower quartzite. (After Emmons.)

and afterwards leached from this by percolating water. The strata are faulted; but since ore is not found in the faults, the necessary conclusion is that they were formed after the accumulation of the ore. An easy passage-way for the metalliferous solutions was furnished along the contact plane of the porphyry and limestone; and this served as an ore channel, in which the minerals were deposited, and from which they penetrated both the porphyry and the limestone,

¹ Monograph, U. S. Geol. Survey, Vol. XII., 1886, *Geology and Mining Industry of Leadville, Colorado*.

but particularly the latter, replacing it atom by atom. According to this explanation, the vein is, therefore, partly an ore channel, partly a replacement deposit, and not a contact vein, as might at first appear probable, although there seems every reason to believe that the intrusion of some of the igneous rocks in the neighbourhood furnished heat to the percolating waters.

The Leadville mines have exhausted the best of their easily mined carbonate; and in the future the output from this district will probably continue to decrease, as it has in the past few years. However, other mines are in operation, and new ones continually being opened. What permanent effect the recent fall in price of silver will have upon these mines cannot at the present time be stated; but it will not be surprising if it serves to close many of the lead-silver mines, and to reduce the output of lead from these sources.

Other Western Lead Mines.—The lead veins of the west are practically all argentiferous galena; and the description of the Leadville mine, together with that of the Eureka and other mines in the chapter on silver will serve to illustrate these modes of occurrence. Utah is next in importance to Colorado, and some of the mines of this territory, as well as of Idaho, have already been mentioned. Idaho is producing large quantities of this metal, principally from the famous Cœur d'Alene mine, which, in 1891, had an output of about 66,000,000 pounds of lead from a low-grade silver-lead sulphide, which exists in great quantities, and promises in the future to increase in importance. The ore occurs in metamorphic quartzites and schists which have been folded and faulted, and the gangue is siderite. Montana, Arizona,

and New Mexico also produce lead from their argentiferous galena mines ; and, in smaller quantities, this metal is obtained from the other states of the Cordilleras.

Foreign Lead Mines. — Spain is the leading lead-producing country of the world, and here, as in the United States, there are two sources, — the argentiferous and the non-argentiferous ores. The most important non-argentiferous galena district is in the province of Jean, which produces nearly two-fifths of this class of Spanish ore. Here the lead occurs in true fissure veins, which traverse a series of nearly horizontal Triassic sandstones, and an underlying granitic mass. A very little silver and some blende occur, the gangue being quartz. Of even more importance than this district is the province of Murcia, where the ore is found in nearly vertical fissure veins traversing Silurian slates, limestones, and intrusive trachytes. The ores are partly argentiferous, partly non-argentiferous galena, in a gangue of quartz, calcite, and barite. A third important mine is in the province of Almeria, where galena, chiefly non-argentiferous, occurs in metamorphic rocks. Portugal has deposits not unlike those of Spain, but of much less importance.

Germany produces lead, usually argentiferous, from the famous veins which have already been mentioned under silver, in the Harz, Erzgebirge, etc. (Clausthal, Rammelsberg, St. Andraesberg, Freiberg, etc.), and also from the Rhenish provinces, particularly Westphalia. Here galena occurs in nodules and grains cementing a Devonian sandstone ; and near Cologne in Silesia lead sulphide, accompanying blende, is found in limestone. The most important source of this metal is in the fissure and segregation veins of the great mining districts, already referred to, where

copper, zinc, silver, lead, and other metals all occur together. In Europe, the next most important lead-producing country (Mexico and New South Wales are more important) is Great Britain. Both the Cornwall and Devonshire districts are lead-producers, but they are losing importance in this respect. Twenty-five years ago Devonshire had an annual output of over 1000 tons of lead, and Cornwall over 6000 tons, but now the output is much less. Elsewhere in England galena is found in flats and fissures in limestone. In north England two sets of fissure veins cross the Carboniferous limestone, and from these there are branching flats, which sometimes lead to caverns, these being connected with the fissures by thin stringers or leaders. The gangue is calcite and quartz, and it also contains some blende. Nearly the same occurrence is noticed in Yorkshire, and lead is also found in Wales, Scotland, and Ireland, in nearly the same modes of occurrence as in England.

In Italy and Belgium galena is found associated with zinc blende in modes of occurrence which are described in the latter part of this chapter. On the mainland of Italy galena also occurs in gneiss with very little blende, and in Belgium a lead vein crosses both the Carboniferous limestone and the Coal Measures and sends branches between the contact of the two. Austria-Hungary produces both zinc and lead, from the large veins, already mentioned in a previous chapter, and from a deposit of dolomite. Neither Russia, Sweden, nor France are of marked importance in the production of this metal, but each produces some. The supply from Russia is obtained partly from argentiferous galena veins and partly from the Polish zinc-lead deposits. Sweden produces argentiferous galena from the metamor-

phic rocks, and France also has argentiferous lead veins crossing metamorphics and eruptives.

Important deposits of lead occur in New South Wales, but we know little about the mode of occurrence there, excepting that the supply comes chiefly from silver-lead mines. Mexican lead ores are partly smelted in this country, and our knowledge of the position of the industry, as well as the occurrence of the ore, is obscure.

Origin of Lead Ores.—Like all metals, the original source of this one was probably igneous rocks, although it has come into its present position in a variety of ways. The metal easily oxidizes, and forms soluble salts, which readily find their way into sedimentary rocks. It may be said that lead deposits are found in three principal modes of occurrence: first, in fissures or other cavities through which metalliferous solutions pass; secondly, in segregated veins where rocks are metamorphosed; and thirdly, in local deposits derived locally from mineral originally disseminated. The first two are generally argentiferous, while the third is usually associated with zinc. These occurrences are more fully described in the chapters on silver and zinc.

Uses of Lead.—This metal finds numerous uses in the arts, and these are being extended and increased every year as the output increases. White lead, the carbonate, to be used in paint, still continues to be the most important use of lead, and litharge, the oxide of lead, is also made into paint; but much of the supply of this metal is manufactured into pipe and sheet lead for plumbing and various other purposes. These latter uses of the metal are favoured by its low melting-point, its softness, the ease with which it can be soldered, and the fact that it does not rust extensively.

An alloy of lead and arsenic¹ makes lead harder, more fusible, and gives to it the habit of assuming a spherical form when dropped through the air. This alloy is used in the manufacture of shot, and this industry calls for large annual supplies of lead. Other alloys are used for various purposes, but the only very important combination is the type metal alloy, which is a mixture of lead and antimony, at the ratio of 76 to 24.² This reduces the melting-point below the average of the two, makes the alloy harder than lead, and gives to it the power of expanding on cooling so that it can be cast, a power which lead alone does not possess. The manufacture of type metal is a delicate process, since if too much antimony is used, the alloy is too hard, and it becomes too soft if the proportion of antimony is too low. Under the heat of melting to form the alloy, the antimony may be partly oxidized and lost, and this has to be avoided by careful methods.

The price of lead has steadily decreased, with some fluctuations, since 1870, when it was 6.25 cents a pound, to 1892, when it averaged 4.09 cents for the year, but in December was 3.80 cents. During this time it has never been above 6.55 nor below 3, but has averaged about 5 cents.

Production of Lead. — The available statistics for this metal are not so complete as for those previously considered, nor is the metal of as much importance. Since the lead is so frequently smelted from other ores, and since much of it is made into white lead, it is difficult to estimate the value of the industry. The following tables will, however, serve to illustrate the distribution of lead and the changes in

¹ Three parts of arsenic to 700 parts of lead.

² There are numerous varieties of type metal of varying composition.

output of the different districts, and this is the chief object of the tables of statistics in this treatise.

PRODUCTION OF LEAD IN THE UNITED STATES.

SHORT TONS (2000 LBS.).

STATES.	1873.	1875.	1880.	1885.	1890.	1891.	1892.
Colorado	56	818	35,674	55,000	54,500	64,000	61,500
Utah	15,000	19,000	15,000	23,000	18,000	28,000	30,000
Idaho-Montana . . . . .	....	....	....	15,000	33,000	40,000	36,500
Mississippi ¹ valley	22,381	24,730	27,690	21,975	31,351	34,000	37,000
Nevada . . . . .	....	....	16,690	3,500	2,000	2,500	2,500
Arizona-California . . . . .	....	....	..	4,000	1,500	2,000	2,000
Total	42,540	59,540	97,825	129,412	143,876	178,133	178,892

The remarkable increase in the output of Colorado is noteworthy, although since 1889 there has been a considerable decrease. Utah has steadily increased, as has also the Idaho-Montana production. This comes principally from Idaho, and the decrease in 1892 was due to the disastrous strike in the Cœur d'Alene mine, which caused the suspension of mining operations for several months. Nevada shows a marked falling off in lead production, as indeed it does in nearly all industries. During the year 1892, in addition to the output above enumerated, 9392 tons of lead were produced by other states and territories, chiefly from New Mexico, and about 39,608 tons were produced from Mexican ores smelted in this country.

¹ The estimate for the Mississippi valley includes all of the non-argentiferous ores; but most of them are from the states in the lead-bearing district of the Mississippi valley, although a small amount comes from the Appalachian states.

The following table from the census statistics, based upon a study of the mines and an estimate of the lead contents, shows the distribution of the lead production by states:—

LEAD PRODUCTION IN THE UNITED STATES, 1889.

STATES.	SHORT TONS (2000 LBS.).	VALUE AT PLACE OF PRODUCTION.
Colorado	70,788	2,101,014
Missouri	44,482 ¹	1,571,161
Idaho	23,172	1,042,629
Utah	16,675	763,329
Montana	10,183	456,975
New Mexico	4,764	170,754
Kansas	3,617 ¹	103,236
Arizona	3,158	98,747
Nevada	1,994	72,653
Wisconsin	1,678 ¹ .	64,062

PRODUCTION OF LEAD BY THE UNITED STATES.

YEARS.	SHORT TONS (2000 LBS.).	MEXICAN ORE SMELTED IN U.S.	TOTAL VALUE AT NEW YORK.
1825	1,500	....	...
1835	13,000	....	....
1845	30,000	....	....
1855	15,800	....	....
1865	14,700	....	....
1870	17,830	....	....
1876	64,070	....	....
1881	117,085	....	\$11,240,160
1886	135,629	....	12,667,749
1889	157,397	25,570	16,137,689
1890	143,876	18,124	14,266,703
1891	178,133	23,867	17,574,000
1892	178,892	39,608	17,917,000

¹ Lead ore.

With some fluctuations the United States has thus steadily increased its output since 1825; but between 1870 and 1880, when the mines of the Cordilleras became of importance, there was a very striking increase. In 1892, 142,087 tons of the total lead product came from desilverized ores.

PRODUCTION OF LEAD IN THE WORLD.

METRIC TONS (2204 LBS) ARE USED FOR ALL BUT THE UNITED STATES AND MEXICO, WHERE SHORT TONS ARE USED.

COUNTRIES.	1885.	1887.	1889.	1890.	1891.
Spain	78,986	119,932	162,000	163,838	235,000
United States . . .	129,412	145,212	157,397	143,876	178,133
Germany	93,134	94,921	100,601	101,781	95,615
Mexico ¹ . . . . .	..	15,488	25,570	18,124	23,867
New South Wales ² .	194	.	35,146	41,996	56,304
Great Britain . . .	38,390	38,411	36,189	34,139	32,731
Italy	16,461	17,795	18,165	17,768	18,500
Austria-Hungary . .	10,625	9,605	10,603	9,552	8,683
Russia	714	988	578	838	900
Sweden . . . . .	.	282	254	310	299
Canada . . . . .	....	93	75	51	267

¹ Mexican statistics are not obtainable, because part of the ores are smelted in this country. Recently smelters have been established in Mexico which *The Mineral Industry* estimates will produce in 1893 about 45,000 tons of lead, having smelted something like 35,000 tons in 1892. The statistics for Mexico are based upon the lead product from ores smelted in the United States, and are therefore far below the truth.

² No statistics are at hand for the output of lead in New South Wales, the estimate given above being the exported lead, and it is consequently less than the actual production.

The United States includes only lead of domestic production, excepting in 1885, when Mexican ores are included.

A remarkable increase is noticed in the Spanish production, which has exceeded that of the United States, and given to Spain the first place, which the United States held for awhile. The rapid increase in the production of New South Wales and the steady decline of the British production are also striking. Mexico should probably hold fourth place in the table, although exact statistics cannot be given. The total production of lead in the world in 1891 was probably about 650,300 tons.

Zinc.

General Statement — Zinc is found chiefly in the ore sphalerite, or blende, the sulphide of zinc; but in nearly all mines of this metal other ores, chiefly weathered forms, are found, the most important of these being willemite, the silicate; calamine, the hydrous silicate; and smithsonite, the carbonate. In the New Jersey mines the ore is the red oxide zincite, and willemite, with the zinc-iron oxide franklinite. Blende occurs usually in association with galena, the latter generally predominating in the fissure veins, the former in local deposits derived from the enclosing strata. The former mode of occurrence has been described in the chapter on lead, and some of the descriptions which follow, being principally of lead-zinc deposits, must be considered to apply, in general, to lead. When blende is associated in minor quantities with lead, it can be extracted where economic methods are in use, but in our western silver-lead mines, blende is not found in sufficient quantities to be of much value. Therefore the Cordilleras have produced practically no zinc, although this metal may exist there as veins of blende,

which have escaped the notice of the prospectors, who would not be familiar with its appearance, the ore being non-metallic in lustre. In distribution, zinc differs widely from the last four metals, the chief source being the states of the Mississippi valley and one or two eastern states, notably New Jersey and Pennsylvania.

Zinc in the United States.—No further description of the lead-zinc deposits of the Mississippi valley is called for, since the blende and galena are found together in the same stratum, often in intimate association. Nevertheless, especial attention is called to the description in the preceding section of this chapter, for comparison with the mode of occurrence in some of the foreign zinc mines. From this general region the chief supply of zinc comes from the Joplin district, in southwestern Missouri, and across the line in Kansas, where much progress has recently been made in the exploration of the deposits in the Keokuk group.

Next to the mines of the Mississippi region the New Jersey zinc deposits are the most important in this country. This district includes two general mining areas situated close together, in Sussex County, one at Franklin Furnace, the other a few miles south of this at Ogdensburg. In both mines the ore is zincite, willemite, and franklinite, and the gangue calcite, included in nearly vertical beds of white limestone closely associated with, and for a long time supposed to be enclosed in, Archean gneisses. Not far distant from the mines there are igneous masses, and recent studies seem to show that the white crystalline limestones are not Archean, but Cambrian beds, metamorphosed by the intrusion of these igneous rocks, which are mainly granites. In the neighbourhood there are large areas of a blue dolomitic lime-

stone of Cambrian age, which is not metamorphosed, and it is this which is believed, by those who have most recently studied the region, to have furnished the zinc during a complete alteration to white crystalline limestone. In the blue limestone, blende is sometimes found cementing a breccia. The vein itself appears to be of true segregation origin, and the walls are not distinct, but the vein becomes poorer on either side, until only here and there a crystal or nodule of ore is found. Studies of these mines have convinced the author that segregation, as illustrated here, is a process, partly of replacement, partly of crowding the enclosing minerals aside to give room for those which are forming.

Another important zinc mine is found in the Saucon valley, Pennsylvania, and this is also in the blue magnesian limestone, which has been very much fissured and crushed, the ore being deposited between the brecciated fragments. The ore in the upper parts of the mine is calamine, but it changes below to blende. From 1853 to 1876 this mine produced considerable zinc, but since then it has been of very little importance. In southwestern Virginia calamine occurs in crystalline limestone, and probably the ore here also changes to blende. Other zinc mines in the United States are of little importance.

Foreign Zinc Mines. — Considerable zinc is found in Belgium and the Rhenish provinces of the German Empire. The ore in Belgium is chiefly calamine, although other ores also occur. It is found at Bleiberg, in small veins and irregular masses, in a Carboniferous limestone crossed by a fissure vein which has been filled with brecciated fragments, partly cemented by ore, and then later reopened and again filled. Both blende and galena occur there. Near Aix la Chapelle

a bed of zinc occurs in Carboniferous dolomitic limestone, which it has partly replaced. The ore is calamine occurring in lake-like depressions in the strata. This region, which was exploited in the fifteenth century, has produced more than 1,500,000 tons of remarkably pure zinc ore. Near Cologne this metal is found, in the form of blende, with galena, in basin-like depressions.

A very important zinc-producing region is in Silesia, in Germany, and extending into the neighbouring country of Poland. Here both calamine and galena occur in troughs, in a dolomite (*Muschelkalk*), evidently the result of concentration from the dolomite. The calamine changes below to blende, and kernels of this mineral are found enclosed in calamine, showing plainly that the latter is derived from the former by weathering. This same bed of *Muschelkalk* produces zinc elsewhere in Germany, and blende is found also in the Black Forest, replacing fossils, and also in the various lead mines of the nation. The chief supply of this metal in Germany comes, however, from Silesia and the Rhenish provinces.

The statements concerning the lead occurrence of Great Britain apply also to zinc, since this metal is practically coextensive with the lead. Austria-Hungary has zinc in very nearly the same modes of occurrence as Germany, dolomite being at times the country rock, while, in other places, lead-zinc ores are found in veins traversing metamorphic, igneous, and sedimentary rocks. Important zinc deposits occur in Italy, chiefly on the island of Sardinia. Here also the ore is calamine and blende associated with galena, occurring in a dolomitic limestone. Other European countries, notably Sweden, produce some zinc, but none of them are of particular importance. Several zinc-

producing districts occur in Spain, the ores there also being calamine and blende.

Outside of Europe and the United States very little zinc is produced; but it seems hardly probable that this metal is confined to these two districts, and the fact that these are the two most explored and most accessible regions renders this still more improbable. There are no signs of exhaustion of our zinc ores; but if they are exhausted, there need be little fear that their place will not be taken by new discoveries either in our western country, or in some other partly explored region.

Origin of Zinc Deposits.—This metal, like many others, may be said to have a typical mode of occurrence, although it is true that there are variations from this. Ores of zinc, usually as minerals of secondary importance, occur in many of the deposits of other metals, particularly argentiferous galena. In such places the origin of the zinc is the same as that of the galena and other ores, whatever this may be. But when zinc predominates, or forms a considerable percentage of the ore, in the vast majority of important mines the association is with dolomitic limestone. It is not possible to state the exact meaning of this association. Dolomitic limestone is sometimes originally deposited as such, but at times it is the result of a secondary alteration of ordinary limestone. Admit that a limestone thus changing is zinc-bearing, and it is readily conceivable that, as one result of the alteration, the disseminated zinc may be segregated. Magnesian limestones, when originally deposited as such, are very frequently precipitated from solution in saline waters, usually dead seas. Such is the case with the Permian dolomites of Texas; but in other dolomites the evidence points to accu-

mulation in open seas where precipitation has probably not occurred. In these cases the magnesia may have been introduced by organisms which contained it in their tests or calcareous skeletons.

Various hypotheses have been suggested to account for the mode of origin of the galena-blende deposits of the Mississippi valley, and these may with equal force be extended to account for the zinc deposits elsewhere. There is a remarkably uniform association with dolomite, and from whatever source we may assume the original supply to have been derived, and these sources are probably various, subsequent concentration, akin to the concretion of flint in chalk, has been brought about by the gathering together of the zinc from the dolomite, sometimes by metamorphism, as in New Jersey, sometimes by slow changes not strictly metamorphic. Certain of the zinc deposits which occupy basins in the rock seem to have been precipitated in these positions originally, although it is possible that this is merely an appearance simulated by a deposit of secondary origin. These remarks apply with equal force to the associated galena. The striking feature of zinc, and of many lead deposits also, is the general association with sedimentary rocks and their accumulation without the intervention of the more potent vein-forming agencies. In this respect they differ from gold, silver, and copper, and more closely resemble iron.

Uses of Zinc. — This metal, in the state of the oxide forming zinc-white, is used as a base for paint in the place of white lead. Formerly zinc was used for sheathing vessels, but very little is at present supplied for this purpose. For plumbing and roofing, zinc is in common use, and as a

coating to iron this metal is extensively called for in galvanizing.

One of the most important uses is in the manufacture of brass, which is ordinarily composed of from 66 to 73 parts of copper and 27 to 34 parts of zinc. The composition varies entirely according to the use for which it is intended, and, with the variation in proportion, the colour becomes more golden or whiter, according as the proportion of copper is increased or decreased. With an increase in the proportion of zinc, the alloy becomes more fusible, harder, and more brittle. Brass was made long before zinc as a metal was discovered, and Aristotle says that the people by the Euxine Sea made their copper a beautiful whitish colour by mixing with it a white earth found there. Strabo also tells us that the Phrygians made brass in this way.

Another alloy of zinc and copper in common use is white metal, in which zinc predominates. From this, buttons are frequently made. Imitation gold is also made by alloying zinc with a predominance of copper, varying from 77 to 85 per cent of the mass, and this is in common use as "gold-foil" for gilding. Zinc is also made use of in the construction of electric batteries.

This metal is much less important than those hitherto considered, with the exception of platinum, and less is produced in the world. Since 1875 the price of spelter¹ has gradually decreased from an average of 7 cents a pound to an average of 4.63 cents in 1892, and in December of that year the price was 4.40 cents a pound.

Production of Zinc. — The available statistics for the production of zinc are not very satisfactory, for the reason

¹ Spelter is the commercial name for zinc.

that it is frequently not smelted in the same state, or, at times, even in the same country, where it is produced. We have statistics for the production of spelter, but this shows little with reference to the distribution of the metal, which it is the purpose of these tables to illustrate. These statistics are introduced, however, as the best that can be obtained. The first table illustrates the spelter production in this country since 1882, but it will be noticed by comparison with the second that this does not illustrate the actual distribution of the ore.

PRODUCTION OF SPELTER IN THE UNITED STATES.

SHORT TONS (2000 LBS.).

STATES.	1882.	1884.	1886.	1888.	1890.	1892.
Illinois	18,201	17,594	21,077	22,445	26,279	30,300
Kansas	7,366	7,859	8,932	10,432	16,380	23,088
Missouri	2,500	5,230	5,870	13,465	13,530	16,161
Eastern and Southern } States	5,698	7,861	6,762	9,561	11,153	13,751
Total	33,765	38,544	42,641	55,903	67,342	83,300

New Jersey and Pennsylvania furnish the greater part of the supply credited to the eastern and southern states. In 1873 only 7343 tons of spelter were produced in this country.

PRODUCTION OF ZINC ORE IN THE UNITED STATES, 1889.

SHORT TONS (2000 LBS.).

STATES.	SHORT TONS.	VALUE AT MINS.
Missouri	93,131	\$2,024,057
Wisconsin	24,832	400,568
Kansas	39,575	299,192
New Jersey and Pennsylvania . .	63,339	175,052
Southern States	12,906	141,560
Iowa	450	3,600
Arkansas	130	3,250
New Mexico	140	2,520
Total	234,503	\$3,049,799

In 1892 the production from the Missouri-Kansas mines was 155,000 tons, valued at \$3,519,225, showing a marked increase in this industry.

PRODUCTION OF METALLIC ZINC AND ZINC-WHITE IN THE UNITED STATES.

YEAR.	ZINC-WHITE.		METALLIC ZINC.		TOTAL VALUE.
	Metric Tons (2204 lbs.).	Value.	Metric Tons (2204 lbs.).	Value.	
1880	9,171	\$763,738	21,088	\$2,277,432	\$3,041,170
1884	11,797	910,000	34,916	3,422,707	4,332,707
1888	18,149	1,600,000	50,729	5,500,855	7,100,855
1890	....	1,600,000	57,789	7,474,962	9,074,962
1891	....	1,600,000	72,834	8,058,405	9,658,405
1892	....	1,200,000	75,589	7,703,580	8,903,580

PRODUCTION OF SPELTER IN THE WORLD.

LONG TONS (2240 LBS.).

DISTRICTS.	1883.	1885.	1887.	1889.	1891.
Rhine District and Belgium }	123,891	129,754	130,995	134,648	139,695
Silesia	70,405	79,623	81,375	85,653	87,080
United States . . .	32,837	36,328	44,946	52,553	71,662
Great Britain . . .	29,161	24,299	19,839	30,806	29,410
Spain	14,671	14,847	16,028	16,785	18,300
Austria	6,267	5,610	5,338	6,330	6,440
Poland	3,733	5,019	3,580	3,026	3,760

The total production of spelter in the world in 1891 was over 350,000 long tons. That the tables of spelter production possess very little value as illustrations of the distribution of the output, is shown by the fact that Italy has no place in the above table, although it is third in rank of importance as a zinc-producing country, and the ore of zinc is, with the exception of sulphur, the most important mineral production. The ore is entirely exported for reduction, and serves to swell the amount of spelter accredited to other countries, just as in the first table Illinois is the largest spelter-producer, although zinc is not mined in the state.

CHAPTER XI.

MERCURY AND MANGANESE.

Mercury.

California Mines.—Mercury, or quicksilver, is found in paying quantities in but one district of this country, and here, as indeed throughout the world, the universal ore is the sulphide cinnabar, with which native mercury and some other ores are found* in minor quantities. In this country, which for a long time held second place as a mercury-producer, but three states have ever supplied any of this metal; and of these, California is the only important one, the other two, Oregon and Utah, having had a small output for a short time only. Ores of mercury have been found in Nevada, New Mexico, and elsewhere; but, although it is highly desirable to have new mines, none of them have proved important.

It is noteworthy that a metal so important in gold mining should have been discovered in California at about the same time that gold was found there. In 1845 the occurrence of mercury was noticed, and when gold mining began, this metal was at hand in such abundance that California soon took second place in the quicksilver production of the world. The mercury of California occurs in a belt of metamorphic rocks, and in these a number of mines have been opened, the most famous being the New Almaden and the New Idria. These mines have decreased

their output of late years, but, as some others are increasing, the total output of the state in the last year or two has not decreased, although in fifteen years there has been a decrease to about one-third of the output at the beginning of this period.

At New Almaden¹ cinnabar is found in two fissures which unite below, enclosing a wedge-shaped mass of rocks, chiefly slates. Running nearly parallel with this, and a short distance away, is a dike of rhyolite, which is of recent age, and probably the cause of the quicksilver deposit. The cinnabar, which contains some metallic mercury, occurs in a gangue of dolomite, calcite, and quartz, containing also iron pyrite. There is apparently no substitution or replacement, but the ore has been deposited in cavities and has, at times, impregnated the porous rocks through which the fissure passes. Already the mine is below the 1800-foot level, and at this depth a temperature of 88° is encountered, which indicates that the volcanic heat is not yet entirely gone.

The New Idria mine, of the same state, does not illustrate any new point, but the ore occurs there in sandstones. A third important mine of the same region is the Sulphur Bank, which was first opened as a sulphur mine and later developed for mercury. This is an extremely interesting mine, since the vein is of very recent date, and, indeed, is apparently not yet finished. A fissure, filled with brecciated fragments, crosses sandstone, shale, and a capping of augite andesite, and in this the cinnabar serves as a cement to the

*
¹ A description of this mine will be found in the volume of the Eleventh Census upon Mineral Industries, pp. 202-215 Becker's Monograph XIII. U. S. Geol. Survey, 1888, entitled *Geology of the Quicksilver Deposits of the Pacific Coast* contains a very complete description of these deposits.

breccia, at times impregnating the porous walls. Hot water still enters the vein, and it appears that the mineral deposition is still in progress, although the greater part of the work is done.¹ The silica at present being deposited is still soft. Other mines are found in this same district, and some of them were opened in the early fifties. The old veins are practically exhausted and must apparently be abandoned soon, but new ones of promise have been recently opened.

The following table shows the production of the five largest mines since 1850:—

PRODUCTION OF CALIFORNIA MINES.

FLASKS (76½ LBS.).

MINES	1850.	1855.	1860.	1865.	1870.	1875.	1880.	1885.	1890.	1891.
New Almaden . . .	7,723	29,142	7,061	17,194	14,123	13,648	23,465	21,100	12,000	8,200
New Idria	2,000 ²	5,000 ²	9,888	8,432	3,209	1,144	977	792
Redington	3,545	4,546	7,513	2,139	385	505	442
Sulphur Bank	6,372	10,706	1,296	1,608	3,429
Napa Consolidated	4,416	3,506	1,375	4,454

Foreign Mercury Mines.—The most important quicksilver deposit in the world is in the Almaden mine of Spain, which has been worked since prehistoric times. Strabo speaks of it, and Pliny states that 10,000 pounds came from there to

¹ Phillips' *Ore Deposits*, pp. 68, 73, and 559; Becker's Monograph (referred to above), and articles by Le Conte in the *American Journal of Science* as follows: Vol. XXIV., 1882, pp. 23-33 ("The Phenomena of Metalliferous Vein Formation now in Progress at Sulphur Bank, California," Le Conte and Rising); Vol. XXV., 1883, pp. 424-428 ("On Mineral Vein Formation now in Progress at Steamboat Springs," etc.); Vol. LVI., 1883, pp. 1-19 ("Genesis of Metalliferous Veins").

² Estimated.

Rome, each year, it being worked by condemned criminals, who were probably slowly killed by mercurial poisoning, from which miners in almost all mercury mines suffer. Although worked for such a long period of time, the mine is not as deep as the New Almaden, for it has not gone far below 1000 feet. In the mine a temperature of 90° is encountered. The ore is cinnabar, with some native mercury, occurring in bunches and veins, in a quartz gangue containing also iron pyrite and galena. Whether it is a true fissure vein or an ore channel is not determined. There are three nearly parallel veins, sometimes twenty feet wide, separated by thin bands of slate from two to three feet in width, and in the lower levels the deposit is worked as a single vein. The country rock is Upper Silurian slates and limestones underlain by a mass of diorite, which is probably the cause of the deposit.

The following table gives the output from this mine since 1850, the statistics from 1850 to 1870 inclusive being approximate estimates:—

PRODUCTION OF THE ALMADEN MINE.

	FLASKS (76½ LBS).	
1850		20,000
1860		24,000
1870		32,000
1880		41,640
1890		50,202
1891		47,993

The Idria mine, in Austria, is in Jura-Trias conglomerates, sandstones, and slates, which are locally impregnated with cinnabar. By far the greater part of the ore comes from bituminous slates, where it occurs in irregular pockets be-

tween large areas of barren rock. Calcite, quartz, and pyrite also occur. The strata are tilted in places to a nearly vertical position, though not always at such a steep angle, and they are crossed by fissures. Since the mines grow richer as the depth increases, it is supposed that the source is from below, perhaps from some hidden mass of igneous rock. This mine has been steadily increasing its output, from 4100 flasks in 1850 to 15,000 flasks in 1891.

Quicksilver comes also from Italy and from Russia. In the latter country there is a single mine in the province of Ekaterinoslav, which began to produce in 1887; but little is known of this mine, excepting that the ore is cinnabar. Other mercury mines have been worked in Russia in the past, and the discovery of new deposits is announced, but our information concerning them is very limited. A mercury mine is also situated in Servia, and from this source about a thousand flasks a year are produced. A cinnabar mine in the Palatinate, in Germany, was of importance from the fifteenth to the eighteenth century, but no ore is produced from there now. It was found impregnating slate strata which were crossed by intrusive melaphyrs.

Outside of Europe and the United States, practically no quicksilver is produced, although there can be no doubt that veins exist. Some comes from Borneo; and there is a mercury mine in Peru, the Huancavelica, which was opened in 1570. Here the ore occurs in slates and sandstones, and the way in which it impregnates the rock suggests that it was introduced in the form of a vapour. Of the Peruvian mines Bullman says:¹ "Ores of mercury are abundant, but the mines have been abandoned, or only worked spasmodically,

¹ *The Mineral Industry*, Rothwell, 1892, p. 563.

for a number of years. The most celebrated of the mines is that of Huancavelica, which was discovered in 1570, and up to 1790 yielded, according to Castelnau, 104,045,200 pounds of metal, worth \$67,629,380, upon a gross expenditure of \$10,587,000. The discovery of this great mine was of the utmost importance, as it rendered possible the enormous output of the Cerro de Pasco and Cerro Potosi silver mines." Quicksilver is used in the extraction of this silver. In Mexico, mercury has been discovered in a number of places, but no large amounts have ever been produced. The ore is cinnabar, and occurs in limestones and slates, the Guadalcázar mines occurring in the former.

Origin of Mercury. — There is a marked uniformity in the ores of mercury, the sulphide being the almost universal ore unless it is decomposed to native mercury. A striking association of quicksilver deposits with slates, sometimes limestones, is also noticed; but this seems to be accidental rather than a case of cause and effect, for the association is not universal, nor is there any apparent reason for the association, unless, possibly, the organic matter in these strata aided in the precipitation. There are no reasons for believing that the mercury came from these rocks, but some of the sulphur may have been furnished by them. In a number of cases, the relation between the veins of mercury and neighbouring igneous rocks is such that one is forced to conclude that they are the cause of the deposits; and in all cases the position of the ore is such that, even though no igneous rock appears, it is a reasonable inference to draw that such rocks exist at no great depths, having failed to reach the surface, as is very commonly the case with these lavas. Mercurial and sulphurous vapours, accompanied, no doubt, by steam, have

escaped from these igneous rocks by some passage-way, usually a fissure, and upon becoming cooler these have been deposited in the vein. Substances so easily turned to gas, when heat is applied, as the two elements sulphur and mercury, we can readily imagine to be made to adopt this mode of accumulation; and it is interesting to note that the facts in the mines support this hypothesis. Becker, Le Conte, and others have shown that in the Sulphur Bank and other mercury mines, cinnabar is brought up in solution with alkaline sulphides and silica, and from this source deposited in the veins. Nevertheless there is good reason to still hold that the water was charged with these substances from gaseous emanations from volcanic rock. Of primary importance in this connection is the peculiar distribution and the rarity of the metal.

Mercury veins appear, therefore, to be in nearly all, if not in all, cases, contact deposits of the sublimation type, or indirectly deposited from a solution of dissolved mercury of this origin. It is conceivable, however, that, accompanying some volcanic eruption, mercurial vapours may become incorporated in stratified rocks in a disseminated condition and later be segregated.

Their distribution is extremely irregular, and only a few localities may be expected to contain them; namely, regions of recent volcanic activity. The reason why they do not occur more commonly in the neighbourhood of older igneous rocks is probably that the heat is too great for their formation. An igneous mass of granite, for instance, intruded into the strata at a depth of several thousand feet, does not become cooled for many thousand years. In the mean time the sulphurous and mercurial vapours cannot condense in the neigh-

bourhood; but unless they form combinations with other elements, there is a tendency for them to migrate from the parent mass, and become disseminated instead of accumulated. If a fissure¹ is at hand, their escape toward the surface would be facilitated, and the conditions for the formation of a vein would be present; but if this is not the case, it is probable that the substances become disseminated. Still, it is conceivable that, under some circumstances, such deposits might be formed in the neighbourhood of the plutonic rocks; but speaking generally, the regions of recent volcanic action are the seats of quicksilver veins.

Uses of Mercury.—The most important use of quicksilver is in the extraction of gold and silver, by the process of amalgamation, as already described. Its power of forming amalgams with other metals makes it of use in the arts for the preparation of a substance to be used for silvering mirrors and for other purposes. The fact that it is liquid at ordinary temperatures makes it useful in the manufacture of thermometers; and this fact, added to its weight, renders it of especial value in the construction of mercurial barometers. In medicine this metal is used in various forms, chiefly as calomel, while cinnabar and other compounds of mercury are valuable in the manufacture of pigments. For this purpose, it was used by the American Indians and by other early races of people.

The price of mercury, in San Francisco, has varied greatly since 1850. In 1850 it averaged \$99.45 a flask; in 1855, \$51.65; in 1874, \$105.18; in 1883, \$26.83; and in 1892, \$38.80.

¹ Available fissures are not liable to occur near intruded masses of igneous rocks; for if they do, the lava will seek them and itself escape as an extrusive rock.

Production of Mercury.—The following tables show the distribution and variation in supply of mercury. The statistics for the United States are practically those of California. In the table showing the production in the world there are no statistics for Borneo, Servia, Russia, Mexico, and Peru; but the total from these places is not great.

PRODUCTION OF MERCURY IN THE UNITED STATES.

	FLASKS (76½ LBS.).
1850	23,875
1855	31,941
1860	10,000
1865	53,000
1870	30,077
1875	50,250
1877	79,396
1880	59,926
1885	32,073
1890	22,926
1892	27,993

The most productive years in this country were between 1875 and 1881 inclusive; but since then there has been a rapid decline, although, in 1892, owing to the opening of new mines, there was an increase in production making the output greater than in any year since 1888.

PRODUCTION OF MERCURY IN THE WORLD.

FLASKS (76½ LBS.).

COUNTRIES.	1880.	1882.	1884.	1886.	1888.	1890.	1891.
Spain	45,322	46,716	48,098	51,199	51,572	50,202	47,998
United States .	59,926	52,732	81,918	29,981	38,250	22,926	22,886
Austria	10,510	11,668	13,907	15,600	15,689	15,709	16,586
Italy	8,410	4,060	7,743	7,279	9,831	13,021	9,570
Total.	119,168	115,171	101,721	104,148	110,642	101,858	96,985

The steady decline of the United States, the general uniformity of production of Spain, and the gradual increase of both Austria and Italy are striking. Chiefly as the result of the decrease in output from the United States, the mercury supply of the world has suffered a decrease, which the increased production of other districts has failed to equalize. Should we need more mercury, there is every reason to believe that it could be readily supplied; but although the gold and silver industries call every year for more quicksilver, it must be remembered that this demand is not as great as it was fifteen years ago, because the reducing works have on hand large supplies of mercury which have already been used and can be used again and again in gold and silver extraction.

*Manganese.*¹

General Statement.—The ores of this metal, of which there are a number, are practically all oxides, such as pyrolusite, psilomelane, braunite, and wad. Other mineral combinations occur, and these are sometimes found with the above ores. As a metal, and in its mineralogical associations, manganese is very similar to iron, and this is true also of its geological occurrence and distribution. Like iron, manganese is widely distributed; but being a much less common metal, it is not as frequently accumulated into beds. However, when this is done, the ore, in the vast majority of cases, is bedded with stratified rocks

¹ A very valuable and complete account of this metal, treated from the geological, chemical, and economic standpoints, will be found in the report on Manganese, by Dr. R. A. F. Penrose, Jr., Vol. I., Annual Report of the Geological Survey of Arkansas for 1890.

and is frequently associated with iron. In occurrence it differs from iron in being less frequently formed by replacement; but its common position in the earth is the same as that of brown hematite and carbonate of iron; namely, either precipitated or concretionary. The marked similarity to iron has caused a frequent association of the two metals, and a great many of the brown hematites, and other ores of iron, are mangiferous. More or less iron is usually associated with the manganese and there is sometimes enough manganese with iron to make the ore a mangiferous iron ore. There is every gradation between iron oxides and manganese oxides. Manganese-bearing zinc ores and mangiferous silver ores are also found.

Although every state contains them, the actual ores of manganese, occurring in economic quantities in this country, are limited. Since this metal is extensively used in the manufacture of steel, large supplies are mined with the iron and never separated. While this applies with full force to the ores containing small quantities of this metal, it is nearly equally applicable to the mangiferous iron ores, which are exploited, ostensibly as iron mines, but are in reality chiefly valuable because of the contained manganese. Mangiferous silver ores at Leadville, Colorado, are mined for the silver, and the manganese-zinc ores of Franklin Furnace, New Jersey, are also worked for the zinc, but not for the manganese, although this is produced as a by-product. Aside from these sources, practically all of the home supply comes from three states,—Georgia, Virginia, and Arkansas. It will be noticed that this distribution coincides, in a general way, with the iron-smelting region; and one may confidently believe that

if other sources are ever needed, they can easily be found. Indeed, even in the Appalachian belt there are manganese deposits that can be called upon for a supply at any time; and no doubt the metal exists in parts of the far west.

Manganese in the United States. — There is a manganese-bearing belt extending from Vermont to Alabama, skirting the old shore line of early Palæozoic times. This metal is found at several points in Vermont, chiefly at South Wallingford and Brandon. At the former place the ore occurs as nodules, in a clay in Cambrian sandstone, while at Brandon it is found in Tertiary strata, probably derived from the disintegration of this same Cambrian stratum. The New Jersey manganiferous zinc ores are apparently in the same belt; and a deposit of very little value is found, in a similar position, in Lehigh County, Pennsylvania. On the western slope of the Blue Ridge, chiefly in Virginia and Georgia, the most important manganese deposits of this belt occur, although the other states have produced some.

In Virginia there are a number of districts, but only one is of marked importance. This, the Crimora district, in the Shenandoah valley near Waynesborough, has produced about 140,000 tons of ore since it was first exploited in 1867. The ore is principally psilomelane and pyrolusite, in the form of nodules, of varying size, irregularly distributed throughout a bed of clay. Shafts and open-works are both used in the extraction of this and the other American manganese ores.

From here southwards no important deposits are encountered until the Cartersville district of Georgia is reached. In this region almost exactly the same mode of occurrence is observed. Since 1866 over 60,000 tons have come from Georgia, chiefly from this district.

Arkansas also has several manganese districts, but only one, the Batesville, in the northern part of the state, is important. Practically the same mode of occurrence is illustrated here, — a surface clay, the residual product of the disintegration and decay of Silurian limestones, through which the manganese was originally scattered in concretions, pockets, and sheets, in very much the same manner as the nodules and layers of concretionary flint and ironstone occur in chalk and limestones (Fig. 25). By this

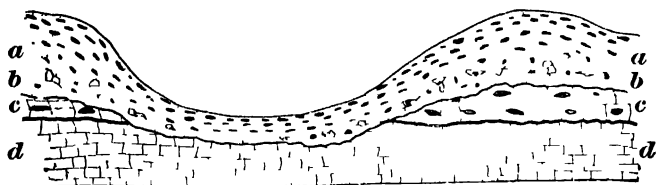


FIG. 25. — Diagram illustrating the origin of the manganese deposits of Arkansas. *d*, non-manganiferous limestone, *c*, manganese-bearing limestone, *b*, disintegrated limestone, *a*, residual clay with manganese concretions concentrated. (Modified from Penrose.)

decay the manganese has been concentrated, and the deposit is rendered valuable by reason of this as well by the change in the nature of the enclosing rock from hard limestone to soft clay. The ore is irregularly distributed, and it is mined by open-works chiefly. Since 1850, 40,000 tons of ore have come from this deposit, and nearly all of this has been obtained since 1880.

None of the other states are of marked importance, although Wisconsin and Michigan contain mines of manganese iron carrying from 2 to 11 per cent of manganese. At Leadville, Colorado, manganese-silver and manganese-bearing iron occur, but the latter is of value mainly as a flux

in silver-smelting and, although some of the manganese is saved, most of it is lost. One mine in California has in the past twenty-five years produced considerable manganese which is chiefly used for local purposes. The ore occurs in the metamorphic Cretaceous rocks of the Coast Range, and, since 1867, about 10,000 tons of ore have been produced. Penrose describes¹ an interesting manganese deposit, which is, however, of no economic importance, occurring at Golconda, in northern Nevada. The ore, which is an impure oxide, is in a lenticular bed in a breccia cemented by calcareous tufa. Both the tufa and the manganese are evidently precipitated from lake waters in a basin from which the water has been evaporated. Many springs contain manganese, and since near this deposit there are hot springs charged with oxide of manganese, Penrose suggests that this may have been the source. Manganese spring waters entering the lake near this point furnished the water with an excess of the oxide of manganese, and this was precipitated after the manner of bog iron ore.

Foreign Manganese Mines. — Canada annually produces a small amount of manganese, chiefly from New Brunswick and Nova Scotia, on the Bay of Fundy, where it occurs in Lower Carboniferous strata. At first the ore was obtained from clays and other products of disintegration of the strata; but, this source being exhausted, the mines are now in the rock, where the manganese is distributed very irregularly, in bunches and seams parallel in general to the stratification, and probably of concretionary origin. In the eastern part of Cuba, several mines of manganese occur in clays, the ore being very rich pyrolusite and psilomelane, often containing

¹ *Journal of Geology*, Vol. I., pp. 275-282.

as high as 56 per cent of manganese, and it is claimed that large beds of this ore exist in the several mines. The present output is shipped to this country. The only other manganese-producing country of the American continents is Chili, where vast deposits are said to exist; but, owing to the difficulties of transportation, they are not fully developed. Moreover, there is no local demand for the ores, and they must be shipped abroad. No manganese was produced in Chili before 1881, and until 1885 very little was obtained. Of the three important districts only one, Carrizal, produces manganese at present, and this was not discovered until 1886. No geological description of the region is available, but it is known that the extensive deposits outcrop at the surface like beds or dikes. Whether these are true beds or veins cannot be stated, but the former seems more probable. Outside of Europe, New Zealand and Australia are the only other notable manganese-producers.

Europe is by far the most important continent in the production of manganese, and nearly every country produces some of this metal. Russia outranks all other countries in this respect, and there the ores are found chiefly in the Caucasus mountains. Little is known of these deposits, but Phillips states that the ore is pyrolusite in Miocene sandstone. In Great Britain manganese occurs with iron, both brown hematite and carbonate, and sometimes alone, as in Merionetshire. Here the ore is found in a volcanic ash, having been derived from the feldspar and accumulated in little veins and pockets in the mineralogical form of pyrolusite and psilomelane. It would be tedious to describe the occurrence in the other European countries, since there is a nonotonous uniformity. France, Sweden, Portugal, Spain, Italy, Turkey, and other

countries all produce some. In most cases the ore is bedded and concretionary, and strata of all ages from the Cambrian to the Tertiary contain it. In the Harz Mountains, in Germany, this metal is obtained from small veins in a porphyry, in Italy from volcanic tufa, but usually the occurrence is in the sedimentary rocks.

Origin of Manganese.—The ore deposits of this metal may occur in almost any kind of rock, although limestone and clay strata are the most common associates. No particular geological age can be said to be manganese-bearing, but, in this country, the most important source is the older Palæozoic strata. Manganese, in one form or another, occurs in nearly all rocks, for it holds the fifteenth place in order of importance of rock-forming elements, and is one of the common metals. It is more abundant in igneous than in other rocks, and this is undoubtedly the original source. Many minerals contain it in small quantities, and in many others it is an important element in the chemical composition. There are several score of minerals in which manganese forms an essential part, and some of them are quite common. These minerals exist in greater or less quantities in the metamorphic and igneous rocks, and by the decay of these their products find their way into the stratified rocks, either directly as sediment, or indirectly from solution in water. The presence of manganese is frequently shown by a brown or black stain, and the fern-like crystal form of one of its ores, known commonly as dendrites, is very common.

Since the metal is very much like iron in chemical behaviour, we find it occurring under the same general conditions. Water takes it into solution and precipitates it in the same manner that bog-iron ore is precipitated. It may

be gathered into regular layers, or it may be disseminated through the strata. If the latter is the case, it may, under favourable conditions, be gathered together at a later period, into beds and concretions of manganese in the same way that iron ores are gathered together to form ironstone concretions. Being less abundant and less valuable than iron, this ore cannot ordinarily be mined when found in this condition; and, indeed, the same is true of much of the iron found in the same mode of occurrence. For successful mining, the ordinary manganese must be concentrated still more; and this has been done by nature, in many places, by the decay of the enclosing rocks and the removal of the soluble parts. Manganese ores, being less soluble than many of the minerals formed by this decay, remain behind with the residue in residual soil, and are naturally more concentrated by the removal of some of the enclosing minerals. Practically all of the manganese mined in this country comes from this source, and in other countries considerable supplies are found in the same condition. Often, however, the final stage of concentration has been omitted, and the mines are in the rock itself; but this is possible only when the ore is very pure, or abundant, or easily and cheaply exploited.

Thus there are three stages in the formation of most manganese deposits, and to these, in many cases, a fourth is added. These are: first, derivation from the decay of crystalline rocks (metamorphic and igneous); secondly, deposition in the stratified rocks; thirdly, concentration into nodules or concretions; fourthly, a still further concentration by the decay of the enclosing rocks and the formation of a residual soil. In some cases the ore may be sufficiently concentrated at the time of actual deposition, as in the Gol-

conda deposit of Nevada; and in others, as in the Harz Mountains, the ore may be derived and directly deposited in veins in the igneous rocks which furnish the manganese. These, however, may be considered exceptional deposits.

Uses of Manganese.—Before the beginning of the Christian era the ores of this metal were used as a colouring for glass, and even at present this is an important use of the oxides. Pure pyrolusite is used to colour glass and also pottery, producing the various shades of violet, purple, brown, and black. An excess of manganese produces the jet-black commonly seen in door-knobs, while a slight amount gives violet, and intermediate amounts purple and brown. Much also depends upon the degree of heat used in the process. The ores of manganese also act as decolourizers, and their introduction into ordinary glass corrects the green colour given by iron. Only pure ores are useful for these purposes, and the greater part of our supply is too impure to be of use in the industry of glass-making.

Until recently the most important use of the manganese ores was in the manufacture of chlorine and bromine, the ore acting as a carrier of oxygen. For bleaching, in the manufacture of disinfectants, as a drier in varnishes, in the printing of calico, and for other purposes, manganese is in common use; but at present more than nine-tenths of the ore mined is used in the manufacture of iron and in alloys. In steel-making two forms of manganese-iron alloy are used, — *Spiegeleisen*, in which 25 per cent or less is manganese, and *ferro-manganese*, in which the amount exceeds 25 per cent. These terms are, however, used variably, and the percentage of the metals in the alloy varies greatly. The effects produced on the iron are very important, but intricate. It pre-

vents the formation of gas cavities during the solidification of the steel, restores carbon, carries off oxygen, and produces other valuable effects.

The price of manganese varies so greatly with its richness and purity, and with the purpose for which it is adapted, that no figures of value can be given without entering into details. The value of the ore varies from eight to ten dollars a ton, being usually between nine and ten dollars.

Production of Manganese. — The following tables illustrate the distribution of the manganese output of the world stated in tons of ore:—

PRODUCTION OF MANGANESE ORE IN THE UNITED STATES
LONG TONS (2240 LBS.).

STATES	1880.	1882	1884	1886	1888	1890	1891	1892
Arkansas		175	800	3,316	4 12	5 339	1,650	6 000
Virginia	3 661	2,892	8,980	20,567	17 646	12 699	16,248	5 000
Georgia	1,800	1,000		6 041	5 568	749	3 573	2 000
Colorado						6 397	964	
California						386	705	
Vermont					1 000	none	49	none
Total	5,761	4,532	10 180	0 113	21 188	25 684	23,416	17,000
Value	\$56 415	\$67,980	\$122 160	\$ 77 6 6	\$27 71	\$110 000	\$239,129	\$170,000

Besides the above a few tons come annually from other states, but this does not materially affect the total. The marked decrease since 1886 in all the districts, excepting Arkansas, is a noteworthy feature of this table. The total for the United States shows a rapid increase, which in 1887

reached the highest point (34,524 tons), since which time it has strikingly decreased. In thirty years the manganese output of the United States has amounted to 300,000 tons. Since the annual consumption is about 50,000 tons, the country produces much less than half the amount consumed. Cuba, Chili, and Russia are the chief foreign sources of our manganese.

In 1889 Michigan produced 81,341 tons of manganiferous iron, and Colorado 2075 tons, valued at about \$3.25 a ton. Colorado produced 64,987 tons of manganiferous silver ores valued at \$3.50 a ton; and the New Jersey zinc ores produced 43,648 tons of manganese residuum valued at \$1.25 a ton, from which 14,124 tons of spiegeleisen were produced.

PRODUCTION OF MANGANESE ORE IN THE WORLD.

METRIC AND OTHER TONS.

COUNTRIES.	1881.	1883.	1885.	1887.	1889.	1890.	1891.
Russia ¹	11,224	17,029	60,458	58,135	77,937	182,346	190,000 ²
Chili ³ . . . . .	....	..	4,041	47,521	28,683	47,986	84,462
United States ¹	4,974	6,255	23,637	35,087	21,592	26,108	23,598
Cuba . . . . .	...	...	..	..	4,000	21,510	21,987 ⁴
Great Britain ¹	2,931	1,308	1,716	14,000	8,997	12,646	9,682
Sweden ¹ . . . . .	..	....	...	8,659	8,645	10,698	9,079
Turkey . . . . .	....	....	..	..	8,000	....	..
Portugal . . . . .	...	....	..	...	5,000	....	....
Italy ¹ . . . . .	....	....	1,802	4,434	2,203	2,147	2,420
Canada ¹ . . . . .	....	....	....	1,130	1,320	1,205	249

The above table is approximate only, since accurate statistics cannot be obtained. Marked fluctuations in the output

¹ Metric tons (2204 lbs.).

² Estimated roughly.

³ Long tons (2240 lbs.).

⁴ Exported.

are noticed, showing that the industry is more or less unstable; but the most striking feature of the table is the rapid increase in production of Russia and Chili. In 1888 the total production of the world was about 153,000 tons; in 1889, about 160,000 tons; and in 1891, approximately 300,000 tons, this increase being chiefly due to Russia and Chili.

CHAPTER XII.

TIN AND ALUMINUM.

*Tin.*¹

General Statement.—A single ore, the oxide cassiterite, is the source of this metal; and it, more than any other equally common metal, may be said to have a typical mode of occurrence. It is found in place, in coarse granite, or in rocks immediately associated with such a granite, and exceptions to this are extremely rare. Being heavy and non-destructible, tin oxide accumulates in placer deposits, exactly as does gold and platinum; and nearly all of the actual tin mines in the world have been discovered by first finding stream-tin and then tracing the ore to its source. The greater part of the tin supply of the world is obtained from gravels, but there are also many mines in the rock.

In distribution, this metal occurs throughout the world, usually wherever granite is found; but paying tin deposits exist only where the ore is concentrated in river gravels or, under particularly favourable conditions, in the bed rock. Therefore tin mines are widely scattered, but comparatively rare. There are none in the United States which are at

¹ A very complete description of tin mines and mining is found in Rothwell's *Mineral Industry* for 1892, pp. 439-462. A description of the occurrence and methods of obtaining tin in the Straits Settlements is found in the volume on *Mineral Industries*, Eleventh Census, pp. 257-264. The Cornwall and Devonshire mines are fully described in Phillips' *Ore Deposits*, pp. 110-154. This description of tin is mainly abstracted from these sources.

present producing; but this industry is an exceptional one; for, although none of the metal is produced, many persons are employed in mining for tin.

Tin Mines of the United States. — This metal has been found in nearly all the states of the Union where granite occurs. Thus cassiterite has been found in the New England and southern Atlantic coast states and in the Cordilleras, but ordinarily in such small quantities that even development is not deemed worth undertaking. Some shafts have been constructed, but so far without bringing any returns worth considering. Serious developments of tin mines have been made in Virginia, where for a number of years stream-tin was found sparingly in the gold-bearing gravels. On the western slope of the Blue Ridge, in the Shenandoah valley, tin was found in place, in 1880; and since then much work has been done in the development of this property, which promises well. Here the cassiterite is found in small veins and in grains, and even nodules a foot or more in diameter, occurring in a coarse-grained granite. The ore also occurs here in quartz veins, associated with wolframite, beryl, and other minerals typical of tin veins. At about the same time that cassiterite was discovered in the Virginia granite, its presence was also noticed in North Carolina, where the ore is found in very nearly the same mode of occurrence as in the Black Hills. Cassiterite is also found here as stream-tin, but neither of these deposits has proved of value as yet. Alabama contains tin ore in stream gravels and also in a coarse gneiss.

The most famous tin-bearing region in this country is that of the Black Hills, where, in 1882, cassiterite was found in place in a coarse-grained granite intruded into slates and

schists. Its occurrence was noticed many years before this in the auriferous gravels of that region. Here the ore occurs disseminated in the granite and in veins of pegmatite, which are composed of quartz and mica in coarse crystals. A large number of mining claims have been located in this district, chiefly in and near Harney's Peak, and several mines have been opened and extensively developed; but up to the present time they have not sold any tin. Immense sums of money have been expended by companies with a large capital, and recently reduction works have been built. These facts indicate confidence, on the part of the managers, that the tin deposits will soon begin to bring profitable returns; but, notwithstanding this, it is the opinion of many competent American mining engineers that, with the existing conditions of inaccessibility, high price of materials and labour, these tin mines cannot be made to profitably compete with the more easily worked deposits in other parts of the world. If this is really true, and there seems good reason to believe that it is, large sums of money have been extravagantly and foolishly wasted in development. The next few years will witness either a large output from these mines or a collapse of the enterprise.

In California, tin has been known to exist, in some of the auriferous gravels, ever since their discovery; and since 1868 tin mining has been carried on intermittently near Riverside, on the San Jacinto land grant, but since September, 1892, this mine has been closed. It is practically the only tin mine in this country which has so far produced marketable tin. Prior to 1892, about 120 tons of this metal have been produced, and since then, to the time of suspension of operations, about 140 tons were obtained. A striking resemblance

is noticed between the mode of occurrence of the tin of this region and that of Cornwall, England; for, in both cases, there is a granite mass cutting slates, and both of these rocks are traversed by quartz-porphyry dikes. All three of the rocks contain tin, but the most promising vein is in the granite. Associated with the ore are tourmaline, quartz, feldspar, and other minerals, and the tin is sometimes in veins, sometimes disseminated. Taking everything into consideration, this was considered, a few years ago, the most promising tin region in the country, but the fact that it has been closed, after a careful examination of its possibilities, indicates that it is not a profitable deposit. Indeed, it may be said that the United States does not at present show any distinct promise of producing tin. Lodes which might be worked in other countries are not uncommon, but the value of labour is so high that they cannot be developed, and so far the country has produced no "tin bonanzas." It is true that prospectors generally do not know tin ore from some of the iron ores, and there are, possibly, valuable deposits at present undiscovered.

Foreign Tin Mines.—Cornwall, in England, the most famous tin region of the world, and this metal has been produced from there for at least two thousand years. At first the cassiterite came from stream gravels, but now all the tin is obtained from mines. The principal sources are granite cutting slates, the slates themselves, and quartz-porphyry dikes which have been intruded into both of these. Associated with the tin are ores of copper, blende, and galena, as well as quartz, feldspar, mica, tourmaline, topaz, wolframite, etc., and the character, and even the kind, of ore varies from one rock to another. The veins are frequently

of the segregation type, crossing all rocks and sending out offshoots, often in such intricacy that a complete network of veins is formed. There is also a great variation in the width of these veins, for sometimes they decrease even to a mere line and then swell to a width of many feet. A peculiar mode of occurrence is noticed at St. Ives and elsewhere, where "carbonas" occur, these being large lenticular masses of granite impregnated with tin, and sloping away from the nearly vertical "parent vein." There seems to be a considerable variety in the occurrence of the tin; for at times the veins are apparently fissure veins, again segregation and often impregnation deposits.

Next to Cornwall, Devonshire has been the most important tin-producing region of England, but at present this source appears to be exhausted. Here the occurrence is very similar to that at Cornwall, but no quartz-porphyry is present. In the eleventh and twelfth centuries Devonshire produced more tin than Cornwall; but while the former has gradually decreased its output, Cornwall has shown a steady increase, from an average of about 300 tons a year in the thirteenth century, to over 9000 tons in 1891. During a period of 690 years, it is estimated that the two districts have together produced 1,128,000 tons of tin; and of this, not much more than 100,000 tons came from Devonshire.

Elsewhere in Europe tin is not abundant, but it is mined in a number of countries. In France it is found in Brittany, where the geology very closely resembles that of Cornwall. The Erzgebirge region in Germany has tin in granites cutting crystalline schists, and in very nearly the same association as in Cornwall. This same tin-bearing belt extends

into Bohemia, in Austria, where, at Schönfeld, tin was mined as long ago as the time when fire setting was used for mining in place of tools. In 1355 this was an important district. Cassiterite is found in granite in Finland; and in Spain tin mines were worked by the Phœnicians in quartz lodes in slates and schists, but they are not now productive. During the reign of Agricola, Portugal produced stream-tin, and in this country tin is also found in the granite.

By far the most important tin-producing district at the present time is that of the Straits Settlements. For at least four hundred years this metal has been exported from there, and it is possible that this was the source of the tin used in the manufacture of the early and prehistoric bronze. In the state of Perak, on the Malay Peninsula, tin has been obtained for at least a century. Granites, slates, and other rocks constitute the mountains of the region, and cassiterite is known to occur in the granite, although this source is not explored or worked. At present the tin produced comes entirely from a small area not exceeding twenty square miles, and from here two-thirds of the output of the Straits Settlements is obtained. Associated with the cassiterite in the gravels are water-worn fragments of granite and tourmaline, which show that here also the uniform geological and mineralogical association, noted above, is preserved, although it is said that tin has also been discovered in place in veins crossing a limestone. The methods of mining are extremely crude, the work being performed by Chinese and natives, but the American process of hydraulic washing is about to be introduced.

On the neighbouring islands of Banca and Billeton the occurrence of tin is the same as in Perak, since these are practically continuations of the same area. Here some

mining has been carried on in the bed rock. Tin is also found in the gravels of Sumatra and Burmah, and it is probable that other sources of this metal will be found in the gravels of other East India islands. If necessary, the output from these several districts could be greatly increased, and it is probable that when these superficial deposits are exhausted, as they must be before a great many years, a more permanent but less profitable supply will be found in the neighbouring bed rock.

Australia is also an important source of this metal, the stream-tin having been noticed soon after the discovery of gold in both Victoria and New South Wales. Every country of this continent has produced some tin, but the only important regions are in New South Wales and Queensland. The source of the ore is the Australian Cordilleras, where it exists, chiefly in granite, in geological association very similar to that of Cornwall. At present, however, these sources are barely explored, the greater part of the supply being obtained from the gravels. The mode of occurrence and origin of the stream-tin is the same, in general, as that of the gold with which it is associated. Even the gravels which are buried beneath lava flows are tin-bearing. Victoria also produces some tin, and in Tasmania a rather unique occurrence exists, the ore being found there in a eurite-porphyry which traverses slates. Vast stores of this metal exist in Australia, both in unworked gravels and granites, and this region will undoubtedly long continue an important source of tin.

In South America the only important tin district at present exploited is in Bolivia, where it has long been known to exist, although hitherto very little has been produced, ex-

cepting as a by-product in silver mining in the Potosi district. Recently, by the construction of a railway, the tin of this section has become valuable, and the output will no doubt increase. The silver-tin deposits occur in a porphyritic diorite, intruded into sandstone, and also in a trachyte cutting slates. Mexico also produces tin, and in the state of Durango the cassiterite occurs in veins in porphyritic trachyte. For many years stream-tin has been produced in small quantities by natives, but the output is not important.

Origin of Tin Ore. — The noticeable features concerning tin are the marked uniformity in character of the ore and the singularly uniform association with igneous rocks, particularly with granite. Other igneous rocks, such as eurite, diorite, and trachyte porphyry, are stanniferous in some cases, but ordinarily the association is with granite. A study of the Cornwall mines shows that these deposits are not of contact origin, nor are they contemporaneous with the intrusion of the granite, as one might at first suppose, for they are found also in quartz porphyries which have been intruded into the granite since it solidified. One is, therefore, driven to the conclusion that these deposits have been derived by subsequent concentration, and their nearly constant association with granite points to this as the common source. In some cases the process of concentration is akin to that of segregation, but frequently the metal occurs in true veins.

Notwithstanding these contradictory facts, it seems very probable that many of the tin deposits are actually of contemporaneous origin with the granite. The position of the tin in the rock, the association with tourmaline, and other facts, point to this conclusion. Indeed, it is not improbable that some of the coarse granitic or pegmatite veins are them-

selves actual intrusions and the source of the tin. The genesis of the ore has not been determined, in spite of the apparent simplicity of occurrence and the great age of the mines. Ordinarily the ore is too disseminated for profitable mining, and consequently a second stage is generally necessary; namely, natural concentration in river gravels, which are the source of by far the greater part of the world's supply of tin.

Uses of Tin. — The manufacture of bronze and of tin plate calls for the greater part of the tin supply, although some is used in plumbing and for some minor purposes. Bronze has already been described under copper. Britannia metal, usually composed of from 82 to 90 parts of tin alloyed with antimony and minor quantities of copper and sometimes zinc, is used for various purposes in the manufacture of cheap utensils, etc. The manufacture of tin plate, which is so useful in tin ware and tin cans, consists simply in coating iron with tin to exclude the air and prevent the iron from rusting. In the United States, and in all European countries excepting Great Britain, the tin consumed is almost entirely imported. This and platinum are the only important metals which we find it necessary to import extensively.

In 1892 tin sold at 20 cents a pound; but since 1885 the price has fluctuated from 16½ to 39.95 cents a pound, with an average price of a little over 20 cents. These fluctuations are due not to variations in supply, but to the operations of the syndicates which control the supply. The tin and tin plate imported into this country in 1891 were valued at \$33,991,668, there having been a steady increase since 1870, when the imports amounted to only

\$9,671,759. Of the total imports for 1891, \$25,900,305 were tin plate and sheet tin.

Production of Tin. — The following table shows the output of tin from the leading districts in the world: —

PRODUCTION OF TIN IN THE WORLD.

SHORT TONS (2000 LBS.).

DISTRICTS.	1880.	1885.	1890.	1891.
Straits Settlements . . .	20,226	25,280	38,019	42,560
Great Britain	8,918	9,331	9,000	9,354
Australia	9,177	9,088	6,415	5,991
Total	38,321	43,699	53,434	57,905

Besides these regions, in 1891 about 1550 tons of tin were produced in Bolivia, not more than 50 tons in Mexico, 720 tons of ore in Austria, 75 tons of tin ore in Germany, and 57 tons in the United States. In 1892 the United States had an output of 65 tons, valued at \$29,827.

*Aluminum.*¹

Occurrence of Aluminum. — No metal has, in the last few years, attracted more attention than aluminum, which has had such a remarkable development that we are hardly

¹ A good account of aluminum, although at present rather old in some respects, owing to the rapid progress in production of the metal, will be found in *Aluminum, its Properties, Metallurgy, and Alloys*, Richards, 1890.

Another account is found in the Eleventh Census volume on *Mineral Industries*, pp. 277-284; *Mineral Resources of the United States*, Day (U. S. Geol. Survey), 1891, pp. 147-163; and Rothwell's *Mineral Industry*, etc., 1892, pp. 11-18.

able to state its present position or predict its probable future. Until a few years ago, it was only a chemical curiosity comparable with many of the rare metals; but now it is already a common metal, pushing its way into the arts in competition with the older and well-established metals. Before 1827 aluminum was unknown, while, prior to '857, it was a decided curiosity, and it remained of no practical importance until a few years ago, when cheap processes for its reduction were successfully introduced. Aluminum is the most abundant metal and the third most common element in the earth's crust. Hundreds of minerals, particularly the complex silicates of alumina, contain this metal in essential combinations, and it is present also, in smaller quantities, in other minerals. In ordinary clay, which is hydrous silicate of alumina, there is an inexhaustible source of this metal; but the mineralogical association is too refractory for profitable separation with the present methods.

The ores which can be made to give up their aluminum easily are very few. Of these, corundum the oxide, is too valuable for abrasive purposes to be used as a source of the metal; diaspore and gibbsite the hydrous oxides, are not found in sufficient abundance; and alumnite the sulphate, although found in some places in the west, particularly in New Mexico, does not serve as an ore, because of the competition of more abundant and available minerals. Until recently the chief source of the metal was cryolite, the fluoride of sodium and aluminum ($\text{Al}_2\text{F}_6, 6 \text{ NaF}$), which occurs in large quantities in Greenland, from which region it has been brought to this country, for a number of years, to be used in the extraction of aluminum. Now bauxite

($\text{Al}_2\text{O}_3\cdot\text{H}_2\text{O}$) is the chief source of this metal, and it is so new for this purpose, and has become so important, that a detailed description is introduced.

Bauxite is, in reality, a limonite in which a part of the iron has been replaced by aluminum; and the true bauxite contains from 50 to 70 per cent of alumina. It was first found in the village of Baux in southern France, and was, for a time, worked as a source of iron; but the ore proved of little value for this purpose. In mode of occurrence it closely resembles limonite, being found both in nodules and in an earthy form. The colour of the pure mineral is white, however, and the mineral is both soft and granular. Bauxite, at the French locality, occurs in limestone, through which it is scattered in beds, nodules, and grains, and it is believed that it was deposited by precipitation in lakes, similar to the mode of formation of lacustrine limonite, and later concentrated by concretionary action. Other deposits in France, Italy, Austria, and Ireland confirm this view, but in some places, particularly in Germany, the mineral is evidently derived from the decomposition of basalt. These facts point to two probable modes of origin for the European bauxite.

In America this mineral is found in Alabama, Georgia, and Arkansas; and when explorations have been carried into other regions, particularly the volcanic and lacustrine regions of the Cordilleras, there seems to be no reason to doubt that extensive deposits will be found. Mining for bauxite was begun in Alabama late in 1891, and the first shipments were made in 1892. The ore is associated with limonites and kaolins, resting on Lower Silurian dolomitic limestone of the Knox series; and in Georgia the occur-

rence is exactly the same, the ore in both cases being scattered through clay and near the manganese deposits. This mineral may have been concentrated from the decay of the limestone, but Dr. Spencer, the state geologist of Georgia, considers it a precipitated deposit formed in lagoons, the mineral having been derived from the solution of portions of decomposed crystalline rocks which exist about twenty miles east of there. Recently Dr. Brauner, state geologist of Arkansas, has announced the discovery of bauxite in large quantities in the Tertiary of Arkansas, where it is found near syenite masses, with which it seems to be associated in point of origin.

History and Metallurgy of Aluminum. — In 1807 Sir Humphry Davy first attempted to obtain aluminum from its oxide; but he was not successful. It was not until 1827 that Whöler was successful in an attempt to separate aluminum by means of potassium, and as a result he obtained a fine gray powder. The same chemist obtained the metal in globules in 1845; and in 1854–1855 Deville, a Frenchman, improved upon this method, and invented a process for the extraction of sodium at a greatly reduced price (from 2000 francs to 10 francs per kilogramme). By substituting this metal for potassium, the beginning of the industry of aluminum reduction was made, and for thirty years this Deville process was used. Deville also introduced the use of electricity in the reduction of this metal, but the high cost of producing this prevented him from anticipating the present electrolytic process. Since 1886 many improvements have been made in the process of aluminum extraction, but none have been more important than the introduction of electricity and the reduction in the cost of sodium by a new process

invented by an American, Castner. A number of patents have been issued for electric processes of reduction, and the price of the metal has steadily fallen. If this continues, aluminum must soon enter the market as a formidable competitor of some of the common metals. The remarkable progress of the industry can be no better shown than by the following table, which illustrates the fall in price:—

COST OF ALUMINUM PER POUND.

1856, Spring	\$90.90
1856, August	27.27
1886	12.00
1889	2.00
1891	90-.75
1892 . . . . .	.50

It is not within the scope of this treatise to discuss metallurgical processes, but it will be of interest to state briefly the process by which aluminum is extracted from the oxide in the works at Pittsburg, Pennsylvania.¹ The principle is that in the presence of a melted fluoride, alumina is decomposed by the electric current, and metallic aluminum liberated. The ore is fused in a flux of fluoride of aluminum and sodium, and a powerful electric current is applied, which liberates the aluminum, while the oxygen forms carbon dioxide with a series of carbon blocks. The fluorides act as vehicles for the alumina. From time to time the metal, which sinks to the bottom, is drawn off, and more ore is added, so that the process of reduction is practically a continuous one.

¹ Extracted from a statement in the *Mineral Resources of the United States*, Day (U. S. Geol. Survey), 1891, pp. 154, 155.

The Uses of Aluminum. — This metal has been heralded as a competitor of iron, copper, and nearly all the common metals, but it seems highly improbable that it will ever seriously compete with most of these. It has properties which fit it for especial uses, for which other metals are poorly adapted. Aluminum is beautiful white in colour, and is not sensibly affected by the atmosphere, which makes it in this respect superior to silver. In malleability and ductility it resembles gold and silver, and can therefore be hammered into sheets and drawn into wire. Without a great reduction in price, it cannot be made to replace iron and copper wire; and the fact that its power of conducting electricity is less than that of copper, makes it probable that it will not replace this metal in electricity. It has been stated that aluminum will rival steel, but this is unfounded, because its tensile strength is only about that of cast iron. Therefore, for purposes which require a high degree of tensile strength, aluminum cannot be used without greatly increasing the bulk; and, since it is unlikely that the price will decrease below that of steel, these uses of this metal will probably never be made. The strongest point in favour of aluminum, aside from its freedom from tarnish and its beautiful white colour, is its extreme lightness. These various properties adapt this metal to certain uses, for which it will perhaps replace some of the brass, copper, tin, nickel, and the white alloys. Still, the position of aluminum must be considered doubtful, although nearly every one admits that it has a bright future.

At present the chief uses of the metal are toys, fancy articles, and ornamental work in machinery. An almost infinite number of such uses are now made of the metal, among which may be mentioned canteens, sword scabbards,

surveying-instruments, race boats, and other purposes where lightness is desired. For plumbing it has not yet come into use, because of the difficulty of soldering. Aluminum wire promises to be valuable for some purposes, since it can be drawn into fine threads and spun, and does not tarnish.

The alloys of this metal have already assumed importance. A small amount added to steel increases its value in several respects, but primarily by preventing air-holes in the castings. There is an increasing demand for aluminum bronze, and for different purposes this alloy is made of different proportions of the component metals. With 10 per cent of aluminum, copper is given remarkable strength, which fits it for purposes where great tensile strength is required. Copper containing about 5 per cent of aluminum is capable of being worked like steel, and there is reason to believe that this may become important. Every year scores of patents are granted for different kinds of aluminum alloys, and already there are many hundred such patents. In a very few years these will be tested and their relative importance determined.

Taking everything into consideration, it may be safely predicted, that, if the price of aluminum can be reduced to ten or twenty cents a pound, which in the light of the past history seems not improbable, innumerable uses, probably chiefly in the alloys, will be found for this metal. It may take the place of tin, which the world can well spare, since it is liable to become exhausted in time, and it may even interfere with the value of zinc, particularly with the use of zinc in the manufacture of brass. Even some of the uses of iron and copper may be replaced by this metal, but there need be no fear that it will seriously interfere with the

demand for the important metals, unless its cheapness becomes as marked as its abundance in the earth. Its very cheapness will serve to prevent its extensive use in place of silver, and, while it may replace nickel for purposes of plating, this metal is making for itself a demand in other directions for which aluminum can scarcely be made to serve. By the introduction of copper-aluminum alloys, both metals will probably have their importance increased. This metal will undoubtedly assume its proper position in the next twenty-five years; and, without accepting the rather absurd claims made by enthusiasts, it seems certain that this will be an important and prominent position among metals.

Production of Aluminum.—The extremely rapid growth of the aluminum industry in this country is shown in the following table:—

PRODUCTION OF ALUMINUM IN THE UNITED STATES.

	POUNDS	
1882		none
1883		83
1884		150
1885		283
1886		3000
1887		18,000
1888		19,000
1889		47,408
1890		61,281
1891		168,075
1892		294,313

The value of the aluminum produced in the United States in 1892 was \$191,303. In 1890 the total amount of aluminum alloys used in this country was 171,759 pounds, while Ger-

many, in 1892, used 616,000 pounds of aluminum bronze. Switzerland produced, in 1892, 629,420 pounds of aluminum; France, 132,000 pounds; and other European nations were also heavy producers; but, since the industry is so recent, statistics are not very full nor valuable on this subject.

The ore bauxite, from which this was obtained, came in America chiefly from Alabama, which, in 1891, produced 3600 tons, and in 1892, 7200 tons, and from Georgia, which produced 3300 tons in 1891. In the latter year we imported 17,936,504 pounds. Baux, in France, produced 20,000 tons of bauxite, in 1888, much of which was exported. There are no statistics available for the production of foreign bauxite.

CHAPTER XIII.

MISCELLANEOUS ORES AND GENERAL REVIEW OF THE METALS.

Nickel and Cobalt.

Mines in the United States.— These two metals occur associated, and much of the cobalt is produced as a by-product in the separation of nickel from the ore. The ores are niccoliferous pyrrhotite, millerite (the sulphide), niccolite (the arsenide), annabergite (the arseniate), and, in New Caledonia and also in other places, garnierite a hydrous silicate of magnesia and nickel, which is a brittle, apple-green mineral. In this country nickel has been found in the metamorphic rocks of Massachusetts and Connecticut; but none is produced from these states at present, and the same is true of a deposit of garnierite which occurs in serpentine in North Carolina. A small percentage of nickel and cobalt is saved as a by-product in the smelting of the lead produced at the mine La Motte in Missouri. Colorado has a non-productive nickel-cobalt arsenide and sulphide mine; and, in Nevada, the same ores are found at Lovelock's station, where a quartz vein, bearing these metals, occurs in an iron-bearing band. Although the mines on this vein have been developed, very little ore is produced at present. There are mines of pyrrhotite in Oregon, and also of garnierite in serpentine in the same state. None of these mines are at present of importance.

Practically all of the nickel and cobalt of the country comes from Lancaster Gap in Pennsylvania, which, until a few years ago, was one of the most important mines of these metals in the world. From early in the last century until 1852, this mine was exploited for copper, but since then its output has been chiefly nickel and cobalt. The ore is niccoliferous pyrrhotite and chalcopyrite, carrying from one to three per cent of nickel and some cobalt. The vein is apparently a fissure, or possibly a segregation vein, at the contact between mica schist and a wedge or lenticular mass of amphibolite. This deposit is fast becoming exhausted, and, unless new deposits are discovered, the district will soon become non-productive.

Foreign Mines.—In Europe the most important nickel-cobalt-producing countries are Norway and Sweden, where niccoliferous pyrrhotite occurs in several places in the metamorphic rocks. Although this region at present ranks third in the world, and has been a producer of cobalt and nickel for many years, it is still of little importance. Austria-Hungary, Prussia, and Great Britain all produce small quantities of these ores, chiefly as by-products in mining of other metals, such as those in the Freiberg district, etc.

The most important mines of nickel and cobalt in the world are in New Caledonia, where the ores were discovered in 1867, although not worked until 1874. In many parts of the colony, garnierite occurs in serpentine, filling cavities and little veins in a decomposed clay consisting of chrome iron and cobalt-manganese iron. This appears to be a product, not of metamorphism, but of later accumulation. Next in importance to this region is that of Sudbury in Ontario, Canada, which has increased its output at a remarkable rate in

the past few years. The ore is niccoliferous pyrrhotite and chalcopyrite, occurring in Huronian gneisses; and, as in the case of the Pennsylvania mine, which it closely resembles, it was at first worked for copper. Very little cobalt occurs here. Since all conditions for profitable extraction exist in this mine, it promises to control the nickel supply of the world.

Cobalt is obtained chiefly as a by-product in the production of nickel, but in some places cobalt ores occur singly. The manganese-cobalt-bearing clay, associated with the New Caledonia nickel, is an instance of this, as is also a cobalt glance found in Chili.

Origin of Nickel and Cobalt. — All of the important deposits of these ores occur in metamorphic rocks, — the sulphides and arsenides in gneisses and schists, the magnesian silicate garnierite, in serpentine. This latter association is noticed in New Caledonia, North Carolina, Oregon, and elsewhere. Whether they are a product of metamorphism, — that is, segregation deposits of metamorphic origin, — or whether they have been derived by a subsequent process of concentration cannot be definitely stated; but the constant association with metamorphic rocks suggests the former as at least a general, if not a universal, explanation.

Uses of Nickel and Cobalt. — Until within a year or two nickel was so unimportant that the opening of a large mine succeeded in closing the smaller ones; but from this time on, the metal promises to grow in importance. There is a certain demand for this metal in the manufacture of cheap jewelry, particularly watches, for German silver, for coinage, and for purposes^h of plating. The latter use has been steadily increasing, and the rapid introduction of bicycles has been largely responsible for this. But recently the invention of

nickel-steel alloy has created a new and very important use for this metal. An addition of a small percentage (about 4 per cent) of nickel to steel gives ~~to~~ it a greatly increased toughness and tensile strength. This steel is now being used for armour plates, and will probably be introduced into the manufacture of propeller shafts and other parts of machinery and engines, as well as for gun and cannon barrels. A nickel-copper alloy (20 per cent nickel and 80 per cent copper) is being used as a casing for the bullets of the small-bore guns in use among the European armies. German silver, a general name given to a variety of compounds, is an alloy of nickel, copper, and zinc.

Altogether the future of this metal is very bright, and there seems little doubt that some of the smaller and undeveloped mines of this country will soon begin to produce at a profit. During 1892 nickel varied in price from 50 to 60 cents a pound.

Cobalt is used, in the form of the oxide, in the manufacture of a pigment, the intense and permanent cobalt blue which is used in the manufacture of paints, coloured porcelain, etc. There are also some minor uses, chiefly in chemistry.

Production of Nickel and Cobalt. — The following statistics illustrate the production and distribution of these metals in this country and in the world: —

PRODUCTION OF NICKEL IN THE UNITED STATES.

	Pounds.
1876	201,367
1880	233,893
1885	277,904
1890	200,332
1891	120,848
1892	96,152

The falling-off in production in the past few years is due to the exhaustion of the Lancaster Gap mine and the competition of the Canadian nickel. In 1891 the United States imported 345,286 pounds of this metal. The value of the output in 1892 was \$57,691.

PRODUCTION OF NICKEL IN THE WORLD.

POUNDS.

COUNTRIES.	1889.	1890.	1891.
New Caledonia	3,045,641	3,500,613	5,399,800
Canada	682,773	1,435,742	4,626,627
Norway and Sweden	240,222	162,742	160,000
United States	217,633	200,332	120,848

In addition to the above, Germany, Great Britain, Hungary, and some other nations produced unimportant quantities.

PRODUCTION OF COBALT OXIDE IN THE UNITED STATES.

POUNDS.

1870	3,854
1880	7,251
1891	7,200
1892	8,600

At present, about 200 tons of cobalt oxide are consumed in the world. In 1888 Chili exported 25 tons of cobalt ores (215 tons in 1887), and Prussia produced 33 tons. New Caledonia, and other countries also produced cobalt; but there are no exact statistics, although New Caledonia exports from 2500 to 4000 tons of cobalt ore a year.

Antimony.

This metal occurs in a number of minerals, but the only important source is the sulphide stibnite. The usual mode of occurrence is in quartz veins, either of segregation origin or true fissure veins, but there seems to be no general association of country rock, although slates are often the enclosing strata. In this country antimony has been found in a number of states, but only one, Nevada, is an important producer. Arkansas contains stibnite deposits in the southwestern part of the state, where it occurs in quartz veins parallel to the bedding. In Kern County, California, this ore is also found in quartz veins, but none is produced from there. Antimony ore exists in Nova Scotia and New Brunswick, Australia, Borneo, Japan, which is the chief source, and in nearly all the European countries, principally in Portugal, Spain, Austria-Hungary, Italy, and France. In all of these mines there is a marked uniformity of occurrence, although in some of them other ores of antimony are also found; and some, notably those of Australia, are auriferous.

Antimony is of chief value for the alloys into which it enters; for, although brittle itself, it imparts a peculiar hardness and toughness to some metals, notably lead. Of these alloys the most important is type metal, which is a mixture of lead and antimony. Britannia metal, pewter, and Babbitt metal (copper, tin, and antimony), all contain antimony, and the metal also enters into certain chemical compounds and substances used for medicine. It is also used in vulcanizing rubber. Although valuable in an alloy of lead, antimony makes gold and silver brittle, and even as small an amount as one-tenth of one per cent injures copper very seriously.

The price of antimony varies greatly, since the supplies are local and widely distributed. In 1891 the price fell from 19 to 12 cents a pound on account of rumours of an increased supply from Japan. Since these rumours were unfounded, the price rose to 16.25 cents in December, but it then fell and at several times during the year 1892 sold for less than 12 cents a pound.

The following statistics are the only ones accessible. We have no statistics for the production of antimony from Borneo, Portugal, and France.

PRODUCTION OF ANTIMONY IN THE UNITED STATES.

	POUNDS.
1880	100,000
1885	100,000
1890	257,768
1891	910,000
1892	956,000

The United States in 1891 imported antimony to the amount of \$313,909, and the value of the metal produced by the country was approximately \$45,000 at San Francisco.

PRODUCTION OF ANTIMONY ORE IN THE WORLD, 1891.

	METRIC TONS (2204 LBS.).
Japan	3200 ¹
United States	1000
Italy	782
Austria-Hungary	557
Spain	547 ²

Canada in 1886 produced 603 tons; but since 1888 the output has rapidly decreased, and in 1891 only 9 tons were furnished. Italy in 1885 had an output of 2887 tons. The

¹ Estimated (in 1890, 3173 tons).

² Exported.

total production of antimony in the world was probably not far from 10,000 tons in 1891.

Chromium.

Chromium is not used in the metallic state, but is chiefly valuable for its chemical compounds, particularly the various pigments, — chrome yellow and chrome green, and bichromate of potash, which is used in calico-printing. A small amount of the chromium supply is used in the manufacture of chrome steel, which is remarkable for its extreme hardness, and is used for burglar-proof safes, hard-edged tools, etc.

The mineral is invariably chromite or chrome iron ore, a combination of ferric and chromic oxides in varying proportions, and often containing other substances as impurities. This mineral is one of the products of the alteration of minerals and rocks to serpentine, and it occurs uniformly in association with serpentine. In America, chromite has been found in varying quantities throughout the belt of metamorphic rocks from Maine southwards, wherever serpentine is found. Formerly mines were located in Maryland, and later in Pennsylvania, and, as a result of this, Baltimore became the centre of the chromium industry in this country, a position which it still holds in spite of the fact that the ores in this region are exhausted. At present the only important sources of chromite in the United States are in California, where it occurs in abundance. But, owing to the difficulties of transportation and the distance from the market, these deposits are exploited in a very indifferent manner, and there is very little profit in the attempt to compete in the eastern market with the Asiatic and European chromite.

In the Urals, chrome iron ore is found in a number of places, and it is obtained also from Greece and Austria-Hungary; but by far the most important source is in Asia Minor, near Brusa, fifty-seven miles east of Constantinople, where it occurs in pockets and bunches in serpentine. The greater part of our supply of this ore comes from there.

In 1892 the chrome ore produced in this country amounted to about 3000 long tons, valued at \$30,000, while the ore imported exceeded 5000 long tons, and the imports of chromate and bichromate of potash amounted to over 1,000,000 pounds. We have abundant supplies of this ore, if we ever need to draw upon them, but the demand is limited and the foreign ores are much more favourably situated for exploitation and transportation.

Iron Pyrite.

Although an ore, this mineral is used as a source, not of the metal, but the non-metallic mineralizer, sulphur. This ore is sometimes a source of copper and also of gold, as has already been stated; but iron pyrite proper is of value only for its sulphur, and for this reason it is used in the manufacture of sulphuric acid. The marvellous increase in the demand for this acid, chiefly for the manufacture of kerosene oil and superphosphates, calls for increasing supplies of pyrite. In 1870, 70,000 tons of sulphuric acid were manufactured in the United States; in 1880, 285,000 tons; and in 1892, nearly 580,000 tons. At the same time the amount of iron pyrite mined has increased from 2000⁺ long tons in 1880 to 106,250 tons in 1892. The imports of pyrite in 1892 amounted to 210,000 long tons.

The iron pyrite mines of the United States are located chiefly in metamorphic rocks, slates and schists principally, where the mineral occurs bedded, segregated, and in true veins. An extensive pyrite-bearing belt extends through Maryland, Virginia, and the Carolinas, but at present the principal source of the mineral in this belt is Virginia. Massachusetts has an output of 40,000 tons a year from the Davis mine in Franklin County. In the other New England states pyrite is common, but not much is produced. Indeed, surprisingly little attention has been paid in this country to this common but, when properly treated, often very valuable ore. Much of our supply of pyrite is foreign, coming chiefly from Canada, Newfoundland, and Spain. The occurrence there is not unlike that of the United States, and some of the ores are valuable also for their copper contents. The following table shows the pyrite production of some of the leading countries of the world:—

PRODUCTION OF PYRITE IN THE WORLD, 1891.

METRIC TONS (2204 LBS.).

Spain ¹	283, .4 ¹
Germany	128,288
United States	1,1,105
Canada	59,312
Hungary	50,000 ²
Italy	19,868
Great Britain	15,716 ³

The output of pyrite from the United States in 1892 (107,985 metric tons) was valued at \$357,000.

¹ Exported.² Estimated.³ In 1866 Great Britain produced 137,622 tons.

General Review of Metals.

Reviewing briefly, it may be said that silver and silver-bearing lead ores are found in a wide variety of associations, chiefly, however, in true veins, and in these, associated very commonly with other ores such as copper, zinc, tin, and gold. The ores of lead are numerous, but this metal is found almost invariably as the sulphide, or some mineral derived from the alteration of this. Aside from the argentiferous galena, lead is found abundantly in non-argentiferous galena, in association with zinc blende, or some mineral derived from the alteration of these; and in such association the mode of occurrence is almost uniformly in dolomitic limestone. Copper is also found in many diverse positions in the earth and in numerous mineralogical associations; but the two chief sources of the metal are native copper in one district and the sulphide in many districts. The latter ore frequently bears gold and silver, and it is not uncommon to find it associated with other ores as, for instance, in the famous English and German mines. One striking feature connected with copper ores is their almost universal association with igneous rocks, which appear to be their source, sometimes by the formation of contact accumulations, but more commonly by subsequent aggregation.

Iron has numerous modes of occurrence, dependent upon a variety of circumstances, not the least important of which is the character of the ore itself. Brown hematite is typically precipitated; red hematite is sometimes altered limonite, sometimes a replacement deposit. The carbonate is prevailingly concretionary in occurrence, and magnetite is frequently accumulated by segregation during metamor-

phism. Nearly all of these deposits of iron are either bedded or have the appearance of being bedded, as the result of the peculiarity of their secondary accumulation by segregation or replacement. Manganese resembles iron in its mode of occurrence, particularly the brown hematite and carbonate, and the same is true of the ore of aluminum, bauxite. Nickel and cobalt prevailingly occur in metamorphic rocks, chromium typically and almost universally occurs in serpentine, and iron pyrite is also found in metamorphic rocks, chiefly iron-bearing slates and schists.

Few metals have more typical modes of occurrence than gold, which occurs in superficial deposits derived from the disintegration of gold-bearing veins, themselves almost equally typical in the fact that they are quartz veins, bearing iron pyrite, and apparently usually of segregation origin. Gold ore is practically all native; and in this there is a close resemblance to platinum, as there is also in the fact that both occur very commonly in stream gravels. This is the universal source of platinum, but this metal is also found in serpentine rocks, although since little is known concerning the source of platinum, this cannot be definitely stated to be the typical occurrence in the rock. Like gold and platinum, much of the tin that is mined comes from stream gravels, where it accumulates for the same reason that the other two metals do; namely, its high specific gravity and practical indestructibility. In the rock, tin is all but universally found in or near coarse granites, although some tin deposits occur in other igneous rocks. Finally, mercury is nearly always associated with igneous rocks of recent origin, and it is apparently a contact deposit, in part the result of

sublimation. Both tin and mercury occur in typical ores, the first as an oxide, and the latter as a sulphide, and other occurrences may be considered rare.

These generalizations must not be understood to be of uniform application. There are exceptions to nearly all these statements; but they are made as general remarks which have an application in the majority of cases. The examples on the preceding pages illustrate the principles here enunciated, and a more widespread study of ore deposits verifies them even more strikingly. Under the conditions above named, the various ores are usually found; and consequently we may properly conclude that, under similar circumstances, other similar mineral deposits will generally be found; but while we may look to these modes of occurrence for the major part of our ore deposits, we need not be surprised to find wide variations from these types, and the reason for this is to be found in the widespread distribution of ore, in disseminated form, through the earth's crust, as well as the great variety of changes which the crust has undergone.

The United States may be considered the great metal-producing country of the world. In the case of a very few metals, principally platinum and tin, we are practically non-producers, but in the others we hold a high rank. Our country stands first in the production of iron, gold, silver, and copper, the four most important metals; second in the production of lead, zinc, and mercury, which are probably the next most important; either third or fourth in the production of manganese and pyrite; and it holds a minor rank in the production of nickel, cobalt, antimony, and chromium, which are distinctly minor metals. The following table shows the value of the metalliferous output of the country

for 1892. The total metal production of the United States for 1892, exclusive of the *ores* mentioned in the table, was valued at \$318,638,596, while in 1880 the value was only \$201,283,094.

PRODUCTION OF METALS AND METALLIC ORES IN THE
UNITED STATES, 1892.

Pig iron	\$136,806,915
Silver	83,909,210
Copper	37,850,000
Gold	33,000,000
Lead	17,917,000
Zinc	7,703,580
Mercury	1,119,720
Pyrite	357,000
Manganese ore	170,000
Nickel	57,691
Antimony	51,600
Chrome-iron ore	30,000
Tin	29,827
Cobalt oxide	6,450
Platinum	1,750

The distribution of these products in the country is very marked. In only three states, Montana, Colorado, and California, are four of these metals found in sufficient abundance to give the state a rank among the first five; and if chromium be excluded, California must be omitted. Montana is the most important state, Colorado second, Michigan third, and California fourth. The following table shows the distribution of the metals, in the first five important states, when there are as many. It will be noticed that but eighteen states are included in such a table; and if manganese is not included, the number is reduced to fifteen. If

iron, manganese, and nickel are excluded, all of these states, with the exception of Michigan, Wisconsin, Missouri, and Kansas, are in the Cordilleras; and the last two of these states are important only for lead and zinc. Thus the distribution of these metals, in abundance, is extremely local. While nearly all of the metals are found in the states and territories of the far west, iron and manganese occur in the east, and zinc principally in the central states. Therefore, the fact that the United States is pre-eminently the country of metals is due chiefly to the peculiarities of the geology in the Cordilleras.

In the following table the relative rank of the states, in the production of a given metal or ore, is indicated by numerals above the estimated value of the mineral product. For iron the value of the ore at the place of production is given, instead of the value of the pig-iron production, which is much greater and differently distributed, this being not necessarily near the mines which produced the ore. The *value* of the iron production gives a different rank to the states from that which is given by *amount* of output, since different ores are of different values. This will be seen by comparison with the tables in the chapter on iron. The actual output of lead, zinc, and some of the minor metals is not well shown in the table; but this will suffice to illustrate the general distribution, which is the object sought in the preparation of the table.

STATES.	1890. IRON ORE.	1891. SILVER.	1891. COPPER.	1891. GOLD.	1899. LEAD.	1899. ZINC ORE.	1891. MER.	1891. MANGANESE.	1891. NICKEL.	1891. ANTIMONY.	1891. CHROMIUM.
Montana . . . .	....	II \$21,139,394	I \$20,537,500	IV \$2,500,000	V \$456,975	...	...	...	...	...	....
Colorado . . . .	.... I \$15,500,921	II 27,305,854	IV 906,230	II 4,600,000	I 2,101,014	...	...	...	...	...	....
Michigan . . . .	....	...	II 13,425,320	...	...	...	...	...	...	...	....
California . . . .	....	...	V 400,000	I 12,600,000	...	...	...	...	...	...	...
Utah . . . . .	....	III 11,313,131	...	...	IV 763,329	...	...	...	...	...	...
Nevada . . . . .	....	4,331,111	...	V 2,020,000	...	...	...	...	...	...	...
Idaho . . . . .	....	IV 5,216,970	...	...	III 1,042,629	...	...	...	...	...	...
Arizona . . . . .	....	...	III 4,730,000	...	...	...	...	...	...	...	...
Missouri . . . .	....	...	...	...	II 1,571,161	I 2,024,037	...	...	...	...	...
Dakota . . . . .	....	...	...	III 9,550,000	...	...	...	...	...	...	...
Pennsylvania . .	III 8,068,684	...	...	...	...	...	...	...	...	...	...
New York	II 8,100,216	...	...	...	...	...	...	...	...	...	...
Wisconsin	IV 1,540,905	...	...	...	...	...	...	...	...	...	...
Alabama	V 1,511,611	...	...	...	...	...	...	...	...	...	...
Kansas . . . . .	...	...	...	...	...	III 299,192	...	...	...	...	...
Virginia . . . . .	...	...	...	...	...	...	...	...	...	...	...
Georgia . . . . .	...	...	...	...	...	...	...	...	...	...	...
Arkansas . . . .	...	...	...	...	...	...	...	...	...	...	...

I Lead ore.

PART III.

NON-METALLIC MINERAL PRODUCTS

CHAPTER XIV.

COAL.

General Statement. — There is practically every gradation from peat to graphite. Many of the brown coals of Texas, and other parts of the west, contain woody fibres, only slightly altered from their original condition, and very closely resembling peat in many characteristics. These grade, sometimes in the same bed, to bituminous coal, which is soft and lustrous; and this in turn may grade into semi-bituminous, a much harder, more compact, and purer coal. In New Mexico, where porphyry dikes have crossed a coal bed, bituminous coal is altered to anthracite; and in Rhode Island, where coal beds have been subjected to marked regional metamorphism, graphite and graphitic anthracite have been produced. A final stage in the alteration would be the formation of a bed of graphite; but we know of no such bed that can be directly traced to this origin, although some of the Rhode Island graphitic anthracites very closely approach this condition.

Briefly, therefore, coal may be said to be altered vegetable accumulations, the degree of alteration producing different grades of coal, even up to anthracite. The alteration indicated by these changes consists partly in compacting the bed, but chiefly in driving off the volatile substances and water and concentrating the carbon. By this process the percentage of carbon is increased, from as low as 5 per cent to 88 per cent,

and even more. The changes which result during this alteration are indicated in the following table of analyses:—

ANALYSES OF PEAT, LIGNITE, AND COALS.

	PEAT	LIGNITE			BITUMINOUS COAL			ANTHRACITE	
	Dismal Swamp	Athens County, Texas	Atascosa County, Texas	Leon County, Texas	Waldrip, Texas	Penn syl vania	Penn syl vania	Penn syl vania	Penn- syl vania
Moisture	78.89	9.10	19.285	14.670	4.55	0.9	1.3	2.74	2.93
Volatile matter	13.84	42.20	59.865	37.320	38.50	25.68	20.87	4.25	4.29
Fixed carbon	6.49	7.37	18.525	41.070	44.50	51.30	67.20	81.51	88.18
Ash	78	41.32	8.325	6.690	12.14	17.77	8.80	10.87	4.04
Sulphur		0.62	2.360	0.250	7.96	4.4	1.83	0.62	0.55

Coal is widely distributed throughout the world, and even in many countries where it is not mined it exists in great quantities. Europe and the United States produce practically all the coal of the world; and, in Europe, by far the greater part of the supply is found in Great Britain, Germany, France, Austria-Hungary, and Belgium. Our own country has a number of important areas.¹ Probably there are not far from 300,000 square miles of coal-bearing strata in this country; but by no means is this all available coal, since over large areas it is either too thin or too impure for profitable extraction. The actual coal-*producing* area, either at present worked or available for the future, is not over 50,000 square miles, and of this only a small part is now being worked.

¹ Detailed descriptions of the coal areas of the United States will be found in the Eleventh *Census* volume on *Mineral Industries*, pp. 343-422, and in *The Mineral Resources*, Day (U. S. Geol. Survey), particularly the volume for 1891, pp. 177-402.

In the Eleventh Census report the coal-bearing strata of the country are divided into seven areas, as follows: (1) the New England basin, including a small section in Rhode Island and southern Massachusetts, having an area of about 500 square miles; (2) the Appalachian district, at present the most important, with an area of 65,000 square miles, and extending from Pennsylvania to Alabama; (3) the Northern area, of about 7000 square miles, in Michigan; (4) the Central area, 48,000 square miles in extent, embraced in the three states, Illinois, Indiana, and western Kentucky; (5) the Western area, a poorly defined region, covering more than 98,000 square miles, and divisible into many minor districts, extending more or less brokenly from Iowa to the Rio Grande; (6) the Rocky Mountain area, of indefinite extent, with scattered basins known to exist in nearly all the states and territories of the Rocky Mountain belt; and (7) the Pacific Coast district, the area of which is also unknown, but in which are included the three states of Washington, Oregon, and California. An eighth area might well be added, to include the Alaskan coal fields, which will soon be developed.

Coal, unlike the great majority of metalliferous deposits, is an actually bedded stratum, formed, as a part of the sedimentary series, in a manner which is more fully referred to in the following pages. Before the development of our western country, coal, properly speaking, and excluding the lignites, was supposed to be the product of a single age, the Carboniferous, and fuels of later origin were believed to be of very local nature and lignitic structure. But the opening of the coal mines in the Rocky Mountains has shown the fallacy of this belief, for here we find beds of all ages, since the Carboniferous, and in all stages of alteration, even to

anthracite. The Cretaceous and Tertiary ages are, in this district, the most favoured with coal beds; but this is doubtless due, in large measure, to the fact that the rocks of these ages are much better developed than any of an age subsequent to the Carboniferous. With the exception of thin seams in the Lower Carboniferous and Devonian strata, there are no coal beds in rocks lower than the Coal Measures.

New England Coal Basin. — This region is of interest, not for the amount produced, but for the peculiar nature of the coal. Although never a heavy producer, this region has been worked, more or less continuously, for a long period. Unlike the greater part of our coal, the beds of this district are highly tilted, and some of the mines have extended to a considerable depth. A few thousand tons are annually produced, but this burns with such difficulty that it is of use only where there is a strong draft, as in a blast furnace; but this difficulty is partly compensated for by the length of time which it burns and the large amount of heat furnished. A very peculiar industry for a coal region has been recently begun upon the basis of the graphitic nature of these anthracites. This is the manufacture of pipe-coverings, stove-facings, stove-blackings, and paints, which shows the peculiar condition of the coal beds.

The graphitic nature of the anthracite is due to the metamorphism of the coal-bearing beds, by mountain-building forces, which have, by folding and faulting, resulted in altering the nature of the enclosing rocks, in some cases to well-defined schists. A considerable thickness resulting from folding is noticed in some of the beds of coal, that at Portsmouth being from three to ten feet thick; and it is not impossible that, in some of the less metamorphosed

parts of this area, valuable coal beds exist beneath the drift coating. This area may be considered a part of the coal-bearing series of Nova Scotia, the age being the same, and the conditions of formation similar, but the metamorphism being much less in the latter district.

Appalachian Coal District. — In this area are included the coal fields of Pennsylvania, Ohio, Maryland, Virginia, West Virginia, eastern Kentucky, Tennessee, Georgia, and Alabama; and the Coal Measures are practically continuous from northern Pennsylvania to western Alabama. The coal beds follow the folds of the Appalachians and extend into the level plateau country at the western base of the mountains. While this coal is confined to a single age, the Upper Carboniferous, it is not a continuous layer, but a series of lenticular beds at different horizons in the Coal Measures, varying in extent and in thickness, sometimes gradually, sometimes abruptly, from a fraction of an inch to several feet. A thin seam may thus become thicker, in a given direction, and then again lose thickness; and, in the shaft sunk to a coal bed, numerous seams of coal, of varying thickness, may be encountered.

This coal was first discovered in Virginia in 1701, in Ohio in 1755, and in western Pennsylvania in 1759. The first coal mines regularly opened in the country were near Richmond, Virginia, in 1750. There are two kinds of coal in this district, the bituminous (including semi-bituminous) and the anthracite, both of which occur in the same series of rocks, the Coal Measures of the Carboniferous, but in different parts of the district.

The anthracite fields, which produce practically all of this kind of coal in the country, are confined to the eastern

part of Pennsylvania, where there are three general regions, the Wyoming, Lehigh, and Schuylkill, which are properly divisible into five well-defined fields or basins. Coal was first discovered here in 1790, and the first shipments were made in 1800; but not until 1825 was the region made to produce extensively, since the difficulty of burning the coal prevented consumers from attempting to use it. The reason for the occurrence of anthracite in this part of Pennsylvania, and its absence elsewhere in the district, is that the coal basins here have been subjected to a certain amount of metamorphism by the folding which has produced the Appalachians. This folding is far less than that to which the Rhode Island-Massachusetts basin was subjected, but was sufficient to drive off much of the water and volatile matter and produce anthracite. It is probable that considerable quantities of this coal have been removed by the extensive denudation to which the Appalachians have been subjected since their formation.

The following table is of interest, since it shows the increase in production of anthracite, in these fields, from the very first. Between 1820 and 1891 inclusive, the output of this region has amounted to 779,639,326 long tons, and the Wyoming district is the most important of the three.

PRODUCTION OF ANTHRACITE IN PENNSYLVANIA.

	LONG TONS (2240 LBS.).
1820	365
1830	174,734
1840	864,379
1850	3,358,889
1860	8,513,123
1870	16,182,191
1880	23,437,242
1890	36,615,459
1891	40,448,336

The bituminous field of the Appalachian area is far more important, in point of output, than any of the other regions; and in this Pennsylvania is the greatest producer. This does not necessarily mean that there is a greater supply of coal here than elsewhere, but that there is a better market and consequently a greater development of the possibilities. The iron industry is largely responsible for this. Where coal is not found iron cannot be profitably mined, excepting under conditions of exceptional facilities for exploitation and transportation, which admit of the shipment of the ore to smelters near the coal supply. Both coal and iron occur in this belt; and in development the two industries have progressed together, so that, at present, both iron smelting and coal mining are carried on, in this district, on a very extensive scale. So fixed is the industry of iron smelting here, that, even though the iron supply may decline, as it has and will continue to do, it will probably continue to increase and be fed with iron from outside, while the industry of coal mining will increase. There are other factors to be considered also, chiefly the fact that this region was the first to be developed industrially, and that it is favourably situated for transportation of coal and articles manufactured by the aid of coal.

In no state is the value of iron mining to coal production better shown than in Alabama, where, in 1870, the output of coal was only 13,000 short tons; in 1880, 380,000 tons; in 1887, about 2,000,000 tons; and in 1891, 4,759,781 tons. A comparison with the statistics of iron will show the relation of the two products. West Virginia has also had a remarkable increase, from 1,568,000 short tons in 1880, to 9,220,665 tons in 1891. Nearly all of the other states of the Appalachian district show a marked increase in coal output, and this

is largely attributable to the increase in the output of iron manufactures.

Central, Western, and Northern Coal Areas. — There is very little to be said about these areas. The Northern basin is of very slight importance, and in the past ten years it has decreased its output. Of the other two districts, the Central has a much larger output, and the states of both districts have steadily increased their production. The coal beds are in practically horizontal strata of the Coal Measures, and coal mining is, therefore, not usually difficult or expensive. Both the age and the conditions of accumulation, and, therefore, the modes of occurrence, are the same here as in the Appalachian district.

It is doubtful if the division between the Western and Central areas is well founded, since the dividing line is the Mississippi, and the cause for the division is merely that this river has removed the Coal Measures from its valley. Missouri and Illinois belong to practically one geological area, and the division is highly artificial. It would be much better to have for the fifth division the Texas and other post-Carboniferous coals of the trans-Mississippi region.

In the more western parts of the area, and in various portions of Texas, there are Cretaceous and Tertiary deposits of coal and lignite, some of which are mined for local purposes, but most of which are at present of no economic value. They form a reserve supply which can be drawn upon in the future; and some believe, in the very near future. The Texas field illustrates this occurrence, for, aside from a rather small and not very important area of true Carboniferous coal, there are extensive deposits of both Cretaceous and Tertiary fuel in this state. On the Rio Grande, at several

points, both lignite and bituminous coal, of Cretaceous age, occur; and, in eastern Texas, there are very thick beds of Tertiary lignite in the coastal deposits. These are easily mined, but, on account of their position, their impure nature, and friable structure, they do not seem to promise to be of immediate importance.¹

Rocky Mountain, Pacific Coast, and Alaskan Coal Areas.— In these districts, coal, in the form of lignite, bituminous coal, and even anthracite, is found in several areas, and in strata of several geological ages, chiefly Tertiary and Cretaceous, and more rarely Carboniferous. Some of these states have increased their output in the last decade at a remarkable rate, and this section may be considered the coal reserve of the country, for even the larger producers have by no means developed their coal fields to even one-half their capacity. The area and extent of these coal fields cannot be stated, but we know that there are immense supplies. Very little anthracite is found, and this is surprising when the changes through which these rocks have passed are considered. A bed of anthracite, about six feet thick, is found in Colorado, and another exists in New Mexico; in both places the metamorphism being that of contact with intrusive igneous rocks. This coal appears to be of as good quality as that of Pennsylvania. The bituminous coal of Colorado, although of Cretaceous age, is also of excellent quality, and it occurs in thick and extensive beds. There is excellent prospect for the future of this state as a coal-producer, and the same is true of other states in this belt; but the lack of market, and the

¹ These coals and the methods by which they may be utilized are described by E. T. Dumble in a Report on the *Brown Coal and Lignite of Texas*, published by the Texas Geological Survey.

difficulty of convincing eastern people that this fuel is better than lignite, have interfered with the more rapid development of the fields.

On the Pacific Coast the most important state as a coal-producer is Washington, where lignites, bituminous and anthracite coals are found, the different kinds being the result of different degrees of metamorphism caused locally by the intrusion of igneous rocks. With the development of the west these Cretaceous coals will be more and more valuable, and already the output has become important, having increased, since 1885, from 380,250 to 1,056,249 short tons.

In Alaska, coal has long been known to exist, and there is promise of immediate development. The Russians knew of the existence of coal before they sold the territory to the United States, but the industrial and climatic conditions have interfered with its development. There are extensive and thick seams which can be easily worked.

Of foreign deposits, nothing need be said, since no new features are illustrated. Coal is extremely widespread and abundant in all explored continents; and, even with the present rapid production, there need be no fear of an exhaustion of the supply for many centuries to come. Not only are there great reserves in our western territory, but in the continents other than this and Europe, coal, though not produced in great quantities, is by no means scarce. It has been formed ever since the Carboniferous, whenever the conditions were favourable, and this has been by no means an uncommon geological condition. There is good reason to believe that the demand will cease before the supply is exhausted.

The following table shows the distribution of coal in the several areas of the country:—

PRODUCTION OF THE COAL AREAS OF THE UNITED STATES.
SHORT TONS (2000 LBS.).

AREAS.		1880.	1887.	1890.	1891.	Total 1870-1892 inclusive.
Appalachian	Bituminous	29,834,622	55,193,034	73,008,102	77,984,563	933,909,305
	Anthracite,	28,640,819	39,506,255	46,468,641	50,665,431	561,627,269 ¹
Central		8,150,195	14,478,883	20,093,533	20,327,323	254,821,177
Western		3,212,787	10,193,034	10,470,439	11,023,817	138,470,000
Rocky Mountain	Bituminous .	1,067,311	3,646,280	6,150,782	7,185,707	53,848,504
	Anthracite .		36,000	55,000 ²	60,000 ²	....
Pacific Coast		425,170	854,308	1,435,914	1,201,376	12,313,040
Northern		100,800	71,461	74,977	80,073	1,155,289
New England Anthracite,		6,176	6,000		500	..
Total		71,437,883	124,015,255	157,788,656	168,566,669	1,956,444,584

The total value of coal produced by the United States between 1870 and 1892 inclusive was \$2,237,258,218.

Origin of Coal.—That coal is derived from vegetation is proved by a number of indisputable facts. In the first place, its carbonaceous nature is strongly suggestive of this origin, and, in the less altered coals, the vegetable origin is proved by the actual presence of plant fibres, seeds, etc. Even where, with the naked eye, stems of plants and impressions of ferns cannot be seen, unless the coal is too greatly metamorphosed a microscopic study shows the presence of woody fibre and plant remains of one kind and another. Indeed, actual tree trunks are quite perfectly preserved, and, in some cases, although the strata have been tilted and disturbed, these trees rise through the coal beds, at right angles to the stratification, with their roots extending into the clay;

¹ Includes Rocky Mountain anthracite.

² Estimated.

beneath the coal. Such a condition has been observed in the Nova Scotia coal fields and elsewhere. The tree trunks stand where they grew, just as some trunks of trees stand at present in bogs, either partly or completely buried.

These facts prove the point that vegetation is the origin of coal, but in just what manner these accumulations were made is not quite so clear. The accumulation of peat bogs is familiar to all who have dwelt in northern lands. A pond is partly filled with sediment, it then becomes transformed to a morass, and eventually to a swamp, by the growth and decay of vegetation, first reeds, then moss, and finally bushes and trees. Year after year additions are made to the vegetable accumulations, until, finally, a bed of peat is formed; and in the typical peat bed, one of the most important of the bog-forming plants is a moss belonging to the genus *Sphagnum*. This vegetation, dying upon the surface, would not accumulate, for, as is well known, organic remains quickly decay in the air; but beneath water this destruction is arrested and the vegetation even preserved by the various organic acids produced by a partial decay. Thus, it is not uncommon to find tree trunks in swamps, at a depth of several feet beneath the surface, so perfectly preserved that the marks of beaver teeth can be seen, although these were made perhaps several centuries or even a thousand years ago, when the swamp was inhabited by beaver.

One might at first assume that, since there is every gradation between peat and coal, the original condition of coal was actually peat, and this has given rise to the *Peat Bog Theory*¹ for the origin of coal. This may have been the origin of

¹ *On the Vegetable Origin of Coal*, Lesquereux, Annual Report, Pennsylvania Geological Survey, 1885, pp. 95-124.

some coal beds, particularly those of the western Tertiary strata, which were deposited in inland seas and lakes. With many of the Carboniferous coal beds, and also some of those more recently formed, another mode of origin must be sought. By a study of the coal beds it is found, that, both beneath and above, there are clays, limestones, and sandstones of marine origin and containing marine fossils. The coal is therefore directly associated, in point of origin, with the sea. Indeed, there are rapid and striking alternations from coal to sedimentary beds, then to coal, and so on, often for scores of feet vertically. Sometimes the coal beds are thin seams, mere films of carbonaceous matter, but at other times they assume a thickness of a number of feet. Although both overlain and underlain by marine sediments, the coal plants themselves are not marine, but of types which, so far as we know, are at present exclusively dwellers on the land. Therefore we must find an explanation which will account for the accumulation of land plants either in or very close to the sea. Moreover, conditions for the preservation of the plant tissue must be present, and these conditions are evidently the presence of bodies of water, either salt or fresh.

Two possible explanations suggest themselves: one, that the coal plants have been washed into the sea; the other, that they grew on or near the shore line and fell into shallow bodies of water. The first of these, which may be called the *Estuary Theory*, is that rivers carried vegetation down with them, and caused it to accumulate in estuaries and bays at the mouths of the rivers. There seems to be very little reason to doubt that this, like the peat bog theory just described, is an actual cause for some such deposits. In the delta of the Mississippi, vegetable accumulations are en-

countered in borings, and these are the result of the stranding and accumulation of rafts of timber which have been floating down the river for centuries. Even at present, although much of the forest of the valley has been removed, portions of the bank are undermined during the floods of the river, and the trees and bushes which grew upon them are floated off toward the sea. But, while this may be admitted as a possible, indeed as an actual cause, it cannot be extended to include all or even a large number of the coal beds. There are numerous fatal objections to the universal application of this theory. In the first place, a river transporting logs carries sediment also, and beds so formed will be much more impure than coal beds usually are; secondly, such deposits must be local and of a more limited area than many of our coal basins; thirdly, under such conditions the plant fragments must be water-worn and broken, and we could hardly expect to have preserved in abundance, as we really do, even the most delicate parts of very fragile ferns; and, finally, it is not probable that in such deposits tree trunks would grow and be preserved in place as they are in some coal strata.

In support of this theory it may be urged that the coal occurs in basins, or linear areas, which might well be estuaries; but this is also exactly what is demanded by the third theory, which may be called the *Seacoast Swamp Theory*. Aside from the objections urged above, against the estuary theory, none of which apply to this one, it is a notable fact that beneath coal beds there is commonly a clay stratum, called fire clay,* which owes its peculiar properties to the absence of certain soluble salts needed by vegetation; and this suggests strongly that the soils have been robbed of

these elements by plants, and most probably by the plants that have been accumulated in the overlying coal beds. If we assume the existence, during the coal period, of coastal swamps and lagoons, such as exist at present on many coasts, and are well illustrated by the marshes about Newark and Jersey City in New Jersey, all of the facts connected with most coal beds are easily explained. There are in the coal basins even channels similar to salt marsh channels or coastal rivers.

It is also a fair assumption to make, that much of the coal-forming vegetation could grow in such places. At present, only a very few plants can live in salt water, or in places invaded by salt water; but, if one thing has been more plainly taught by geology than any other, it is that animals and plants have changed, not only in form and development, but in habits; and, since it is not improbable that land vegetation came originally from oceanic types, the change in habit here suggested is certainly possible, and we may even say, probable. On the eastern coast of the United States there are a number of phenarogams living, not only on salt marshes, but one, the eel grass, growing and flowering entirely submerged in salt water; and, on the Florida coast, the mangrove tree grows with its roots in salt water. No especial incredulity need, therefore, be felt in considering the possibility of a more widespread adoption of this habit by the Carboniferous vegetation, which differed so markedly from the present types of plant life. It is not, however, absolutely necessary to assume this condition, for it is possible that there existed along the shore line extensive swamps which were either fresh or only slightly saline.

A study of coal deposits indicates not a single, but several explanations for their origin. Some were formed as peat

bogs; some, particularly those of the western Tertiary and Cretaceous areas, were formed upon the margins of lakes and inland seas; not a few were, no doubt, accumulated in sea-shore estuaries; and probably most of the Carboniferous coal beds were formed along coast lines in shallow lagoons, or seacoast swamps, either fresh or saline, and probably both. Attention may be called, in this connection, to the fact that the geological conditions in this country favoured the latter mode of accumulation in the three important coal-bearing ages. During the close of the Carboniferous period a great sea was beginning to be transformed to land, as the foreshadowing of the development of the Appalachian Mountains and the central plateau. Skirting the old, pre-Palæozoic mountain area of the seacoast states, there stretched westward a region of shallow water and low, swampy land, upon which the coal vegetation grew. In the Central area, and in parts of the Cordilleras, the same conditions prevailed: but, in the latter region, these were better developed in Cretaceous and Tertiary times: and here, by the mountain growth, large inland seas and lakes were produced, in which coal beds were accumulated.

Conditions existing in Carboniferous Times. — A number of interesting questions arise concerning the conditions existing in the Carboniferous period. Why do we find such rapid alternations of coal beds with marine sediments? It has been held that this is due to rapid alternations in sea-level, or, rather, land position; that the land rose and fell, now being occupied by swamp plants, again submerged by the ocean, and this followed by other similar alternations of level and condition. This may be true; but so many alternations are called for, none of them producing high land, that some

simpler explanation may be sought. These phenomena may be accounted for by assuming a swampy land area, not unlike the coastal plains of Texas, gradually sinking, but with occasional halts, or periods of less rapid sinking. When land existed, plants grew; but, if the submergence were more rapid than the building up, water prevailed until the rate of sinking was less rapid than the rate of filling. When such a period of slow submergence, or perhaps even absence of submergence, prevailed, sediment filled the bays, vegetation grew upon their margins, lagoons were built behind bars, and salt marshes were formed, just as they are at present, under the same conditions. In this manner the apparent elevations may have resulted from filling rather than actual rising of the land. So, by a gradual submergence, a mere variation in rate will bring about all the conditions of alternation ordinarily noticed in coal beds. This does not deny the possibility of elevations also, for these would cause the alternations even more rapidly; but it does call in question the necessity of a theory which requires a large number and great variety of elevations and submergences, since this necessitates an instability of the land rarely witnessed anywhere outside of local volcanic areas, and our immense coal fields were not formed in such places.

Another question that may be asked is, what were the climatic conditions in the Carboniferous period? It has been very commonly assumed that the climate was moist, tropical in heat, and the atmosphere laden with carbonic acid gas for plant food. The large size, and apparent luxuriance of the vegetation, resembling our present tropical flora, have been appealed to in support of this. That the climatic conditions were different from the present, even as

late as the Tertiary period, is proved by a study of the Arctic regions, where not only animal and plant fossils, but even coal beds, are found in the rocks now situated in a region of perpetual snow. The value of the evidence in favour of these, from our present standpoint, abnormal conditions, has, it seems to the author, been unduly magnified. The evidence of luxuriant Carboniferous vegetation does not appear of so much importance when one has seen the giant trees of California and the primæval forests of Canada. A good soil and a moist, and not too cold climate, will produce striking results in vegetation. It is doubtful if any trees in the Carboniferous period exceeded in size the giant Sequoia of California. Moreover, fossils of animals show us plainly enough that types which are now small throughout the world were once gigantic in size; and the same may be equally true of plants. A new field and a newly acquired habit give to both animals and plants great powers of remarkable development. Before the Carboniferous period practically no land plants existed, and the soil was not, therefore, robbed of its plant food. Moreover, the Carboniferous land was made of a virgin soil just elevated above sea-level. Under such conditions, with a temperate climate, a luxuriant vegetation might easily be developed.

It seems that we must grant moistness to the atmosphere, and the presence of oceans, where now is land, transforming the old mountain areas of the east into islands, makes such an assumption entirely within reason. When one reads the accounts of Russell¹ describing the luxuriant, almost trop-

¹ An expedition to Mount St. Elias, Alaska, *National Geographic Magazine*, III, 1891, pp. 53-204; *American Journal of Science*, XLIII, 1892, p. 178; *Journal of Geology*, I, 1893, p. 233.

ically luxuriant, forest at present actually growing on a moraine which rests *on* a living body of ice, near the terminus of the great Malaspina glacier of Alaska, he is ready to believe that no great revolution of climate is necessary to carry the vegetation of the Carboniferous period as far within the Arctic circle as man himself has penetrated. Transform the highlands of the Arctic to lowlands, and much of the ice will disappear; then add to this a slight increase in the mean annual temperature, and vegetation would find a home there. Peary, Lockwood, and others, state that the land lying north of Greenland is free from snow in summer, notwithstanding the presence of the great Greenland glacier to the south and of a frozen ocean all about. This is due in large measure to the fact that the land is low; and if the mountains and highlands of Greenland were lowered to near sea-level, the climatic conditions of the Arctic would be greatly changed. Climate is strikingly dependent upon geography.

The object in presenting these considerations is not to deny the possibility, nor even to question the probability, of a marked change in climatic conditions in the northern hemisphere during Carboniferous times, but to point out the fallacy of the statement so frequently made, that tropical conditions extended to the poles. Possibly this was the case, but probably it was not, and, in any event, the argument upon which these statements are chiefly based, the resemblance of the coal flora to our present tropical flora, is not of much value after the lapse of time and the striking changes which have taken place in form and habit of fauna and flora since the Carboniferous period.

The question is sometimes asked, why are coal beds not

present in periods earlier than the Carboniferous? and the answer is, simply, that land vegetation had not been evolved in great luxuriance in earlier periods. A current statement, frequently found in text-books, is, that the reason for this was the too great abundance of carbonic acid gas in the atmosphere. According to this assumption, the early land vegetation laboriously extracted this carbonic dioxide, until just the proper percentage remained for the luxuriant Carboniferous vegetation, but too much for air-breathing animals, which came after the atmosphere had been cleared of the deleterious gas by the Carboniferous plants,—having the way prepared for them, as it were. Aside from the logic of animal and plant succession, which is as above stated, and which is readily explained in another way,—namely, normal evolution,—it is difficult to see upon what basis this assumption of an excess of carbonic acid gas in the atmosphere is based. To be sure, carbon taken from the air is sealed in the rocks in the form of both animal and plant remains; but, on the other hand, it is being liberated by the decay of rocks; and it is very doubtful if the supply of this gas in the atmosphere is sensibly different to-day from what it was in the beginning of the Carboniferous.

If we should grant the assumption, for the sake of argument, it would seem that a gradual decrease in amount and luxuriance of vegetation would necessarily follow upon the exhaustion of the carbonic dioxide; but, on the contrary, vegetation has increased in height of development and has certainly not lost in luxuriance. Ever since the Carboniferous the land areas of all the world have been clothed with vegetation, and so they are to-day. Moreover,

if geological interpretations have been correctly made, there is more land at present than ever before, and this land has been continuously increasing in amount since the Carboniferous. The simple fact is, that the greater part of the carbon taken from the air is given back again when the plant or animal dies, and the place of that stored away in the rocks is fully filled by supplies furnished by rock decay.

Uses of Coal. — It would be difficult to make a comparison between the value of coal and iron, since both are so important and intimately related. Probably, however, iron must be considered of more value, since there are so many possible uses for it, and no available substitute, whereas coal is not an actual necessity, although in the present state of industry it seems to be. The importance of the coal industry is shown by the fact that in 1892 coal valued at not far from \$200,000,000 at the mines was produced in this country, and in 1891, 205,600 persons were employed, directly or indirectly, in the production of coal. Of bituminous and anthracite coal, the country produced 171,769,355 short tons in 1892, 49,735,744 tons of this being anthracite, and the balance bituminous (including all varieties of coal excepting anthracite). Our exports in 1892 amounted to nearly 2,500,000 tons, and our imports to a little over 1,000,000 tons. The consumption of coal in the country per capita amounted to 5234 pounds.

Undoubtedly the most important single use of coal is as fuel for heating and cooking purposes; but as fuel in the manufacture of materials requiring heat, immense quantities are called for as well as in the production of energy in the form of steam. Our locomotives and engines for

manufactories and for steamships are consuming coal at a remarkable rate which is every day increasing; and the rapid expansion of electric transportation in small towns and suburban districts is also increasing the demand for this fuel. One of the most remarkable advances in the use of coal is that made in the manufacture of pig iron and steel. Bituminous coal, transformed to coke by driving off the volatile substances in ovens, is rapidly supplanting anthracite and charcoal. Whereas in 1880 only 5,237,741 short tons of coal were used for this purpose, in 1891, 16,344,540 tons were consumed, producing 10,352,688 tons of coke valued at \$20,393,216. A relative decrease must have been caused in the consumption of coal for coal gas by the introduction of electric lights; but the falling off in this respect is more than compensated for by the increased demand for coal in the production of electricity.

It is an interesting question what the future of coal will be. Some predict that the supply will fail us, and these favour more economical methods of production and use; but, while this may be true of localities, and even of some countries, there seems to be no need to fear it in this country, nor in the world, for such a length of time that we need hardly trouble ourselves with the question. The tendency of the present seems to be rather toward a decrease in demand than a decrease in supply. This has not as yet made itself distinctly apparent, nor is it an absolute certainty; but when we learn to economically win our electricity from the wasted forces of nature, the waterfalls, or, as some predict, from heat direct, and then learn to store it for transportation, and to convert it from electrical energy to heat energy, there will come a time when coal

will be found of much less value than at present. This is now little more than a dream, but wonderful things are being done with electricity, and electricians assure us that we have hardly begun.

Production of Coal.—In the production of the metallic minerals the far west was found to be of prime importance, but in the non-metallic products of the earth that section of the country assumes a much lower rank. The reason for this is that already given for the absence of an important iron output in the west,—less a lack of supply than an absence of market, or, in other words, a smaller degree of industrial progress. The following tables of coal output illustrate this distribution and other features connected with the production of coal at home and abroad:—

PRODUCTION OF COAL IN THE UNITED STATES.

SHORT TONS (2000 LBS.).

STATES.	1870	1875.	1880.	1885.	1890.	1892.
Pennsylvania (Anthracite)	15,650,275	23,120,730	26,249,711	38,335,972	46,468,640	49,100,744
Pennsylvania (Bituminous)	7,798,517	11,760,000	21,280,000	26,000,000	42,302,173	41,424,784
Illinois . . .	2,624,163	3,920,000	4,480,000	11,834,459	15,274,727	17,949,989
Ohio	2,527,284	5,447,970	7,840,000	8,734,120	13,203,522	11,560,000
West Virginia	618,878	1,120,000	1,404,008	3,369,061	6,002,800	8,710,878
Alabama . .	10,999	67,200	380,000	2,492,000	4,090,409	5,275,000
Maryland . .	1,819,824	2,623,905	2,692,497	2,833,337	3,357,813	4,036,283
Iowa	263,487	1,120,000	1,792,000	4,012,575	4,021,739	3,820,000
Colorado . .	4,500	98,838	375,000	1,398,796	3,075,781	3,771,234
Indiana . . .	437,870	896,000	1,680,000	2,375,000	3,305,737	3,309,700
Kentucky . .	150,582	560,000	1,120,000	1,904,000	2,483,144	3,020,050
Missouri . .	621,930	840,000	1,680,000	3,080,000	2,437,399	3,017,285
Total for the United States,	33,003,315	53,121,029	73,647,997	112,609,811	56,073,611	171,769,855

Besides these states, four others, Kansas, Tennessee, Indian Territory, and Washington, produce between 1,000,000 and 3,000,000 tons annually, and the first two more than 2,000,000 tons. A noteworthy feature of this table is the rapid increase in the coal output of all the states, but especially of Alabama and Colorado. It is also a striking fact that the three leading coal-producing states in 1870 maintained their position in 1892. These three states, Pennsylvania, Illinois, and Ohio, together produced, in 1892, 123,670,000 tons out of the total 171,769,000 tons produced by the country. Pennsylvania supplied considerably more than one-half the total of the United States, but the percentage of Pennsylvania's output to that of the rest of the country has decreased considerably since 1870, owing to the rapid increase in output in other parts of the country. In twenty-three years the United States has increased its coal output to more than five times the amount at the beginning of that period, or at the average rate of more than 6,000,000 tons a year.

The average cost of bituminous coal at the mines in Pennsylvania in 1891 was \$1.00 a ton, and of anthracite coal \$1.79 a ton. Therefore the value of the total output of 168,566,669 short tons was \$191,133,135. This of course does not at all represent the retail price, after shipping and passing through the hands of dealers, for this price varies greatly according to a variety of conditions, chiefly the distance from the mine and the manipulations of coal combinations.

PRODUCTION OF COAL IN THE WORLD.¹

METRIC TONS (2204 LBS.).

COUNTRIES.	1865.	1870.	1875.	1880.	1885.	1891.
Great Britain,	99,759,618	112,211,531	135,491,837	149,378,744	161,963,736	188,519,767
United States,	24,790,400	29,948,562	48,204,201	66,831,213	102,186,761	133,551,132
Germany . .	28,327,800	34,880,600	48,532,400	59,118,035	73,675,515	94,252,278
Austria-Hun- } gary	2,028,089	8,355,945	13,062,738	14,800,000	20,435,463	27,000,000
France . . .	11,840,000	13,300,000	16,956,810	19,361,564	19,510,530	26,199,745
Belgium . .	11,840,603	13,697,110	15,011,331	16,856,698	17,437,603	19,865,345
Russia . . .	331,000	696,209	1,171,736	3,266,844	4,273,476	7,000,000 ²
Spain . . .	250,000	661,932	610,000	847,128	945,904	1,286,000
All Other } Countries .	97,000	4,041,111	6,258,917	9,979,774	12,389,072	17,126,733
Total for } World .	182,080,000	217,823,000	285,300,000	339,370,000	412,818,000	535,101,000

The rapid increase in output of nearly all the countries is a striking feature of this table; but this is particularly noticeable in the case of the United States, Austria-Hungary, and Russia, and the group of unspecified countries. Spain, France, and Belgium have shown a smaller rate of increase; and the two latter countries have fallen in rank, although they have increased their output. The marvellous increase in the coal production of the United States is especially noteworthy; and it will not be surprising if, in the next decade,

¹ This extremely valuable table is extracted from a more complete one in Rothwell's *Mineral Industry* (p. 84), which has served as the source of many of our statistics. Any student interested in the statistics of mineral production will find this subject admirably and fully presented in that treatise.

² Probably the output of Russia for 1891 was nearer 8,000,000.

this country assumes first place among the coal-producing nations, which it can easily do, if the demand increases sufficiently, since our possibilities are certainly exceeded by no other country in the world. Over three-fifths of the coal of the world is obtained in the United States and Great Britain. In the last twenty-seven years the average rate of increase in the coal output of the world has been about 13,000,000 tons a year.

CHAPTER XV.

PETROLEUM, NATURAL GAS, AND ASPHALTUM.¹

Petroleum.

General Statement. — Petroleum, natural gas, and salt water frequently occur, more or less intimately associated, in stratified rocks. While sandstones and conglomerates are the chief sources of these substances, they are by no means confined to these rocks; but in some places are found in shales, in others, in limestones. The geological age of the petroleum-bearing strata is also variable. In the eastern states this substance occurs chiefly in the Silurian and Devonian sandstones and conglomerates, but some is also found in the Carboniferous strata. Practically no oil occurs in strata earlier than the Silurian. By far the most important single source of oil, at present, is the Trenton limestone horizon of the Silurian, in which the Ohio and Indiana fields are situated. Shales of the Laramie stage of the Cretaceous bear oil in Colorado; and in California the age of the oil-

¹ The statistics and distribution of these substances in the United States are fully treated in the Eleventh Census volume on *Mineral Industries*, pp. 425-591; in Rothwell's *Mineral Industry*; and the various volumes of *The Mineral Resources of the United States*, Day (U. S. Geol. Survey). The geology of the subject is discussed by Orton in the Eighth Ann. Rept. U. S. Geol. Survey, 1889, pp. 475-662. There is also an important discussion of the subject in the Tenth Census, Vol. X., pp. 1-319. Various reports of the State Surveys of Ohio and Pennsylvania also contain discussions on petroleum. A complete bibliography of the subject will be found in Carll's report, Annual Report for 1886, Part II., pp. 830-895.

bearing strata is Tertiary. Thus, although in the early history of the petroleum industry the Palæozoic was believed to be the only source of oil, it is now found to range through all ages from Lower Silurian to Tertiary.

From the very earliest times in the history of this country, the existence of petroleum has been known, by reason of its seepage at the surface, in oil springs; but before the discovery of oil in a well at Titusville, Pennsylvania, in 1859, no petroleum was produced. Immediately after this discovery, explorations were begun elsewhere in Pennsylvania; and these have been extended, practically all over the country, with the result of finding oil in the majority of the states, although the profitable production is confined to a few districts. Many remarkable developments have been made, particularly those in 1885, when the importance of the Trenton limestone was first recognized. There are undoubtedly other fields yet to be discovered; for even in as thoroughly explored a state as Pennsylvania, new fields of great importance were discovered only a few years ago.

Distribution of Petroleum. — Petroleum occurs, in rather limited areas, in various parts of the United States. The well-known oil regions, which produce the greater part of the supply of the country, are the western Pennsylvania-New York field, two fields in Ohio, the West Virginia field, one in Colorado, and one in California. Although a few other states produce some oil, none of these are of immediate promise; but the past history of the petroleum industry is such that it is not safe to make predictions with reference to the possible future of these districts. Outside of the United States, the principal oil fields are in the Caspian region, Canada, Japan, and New Zealand; but the United

States and Russia are far more important than all the others.

Little need be said with reference to the distribution of petroleum, aside from the above general remarks and the statistics in the latter part of this section. Until 1875 all the petroleum of the country came from the Pennsylvania-New York field, which is continuous, and must therefore be considered as one field. Various oil-bearing sands of Devonian age are found there, in irregular areas, and since 1859 they have been productive. Even as late as 1891, important developments were made, in this district, by the discovery of an oil pool called the McDonald field, which, in the latter part of 1891, had a production of 84,000 barrels a day; but this has decreased, and at the close of 1892 the daily flow was about 18,000 barrels. In the last six months of 1891, it is estimated that 6,000,000 barrels of petroleum were produced from this field. Most of the old wells have diminished their flow, and many of them are now non-productive. New supplies will probably continue to be found in this field at intervals; but eventually this will cease to be the case, and the old ones will probably give out. This seems to be the future of the petroleum industry, and already there are signs of its approach.

During 1892, West Virginia increased its output by supplies from newly discovered fields in the same general belt as that of Pennsylvania. Since 1885, Ohio has assumed marked importance in this industry by the discovery of oil in large pools in various parts of the Trenton limestone. In Colorado there is a small area, called the Florence field, which has produced, and still continues to produce, considerable oil from a bituminous shale in the upper strata of the

Cretaceous. The California oil comes from sands bedded with shales of Tertiary age. These oils are quite remarkable from the fact that they occur in highly tilted strata, instead of in nearly horizontal rocks, as is usually the case. In Russia, oil occurs in the region of the Caspian, in Canada in the province of Quebec, and oil is also found in Japan, in Peru, New Zealand, and in small quantities in several European countries.

Origin of Petroleum.¹—There are great variations in the character of petroleum, not only in different districts, but even in the same field. Some are dark and heavy, others are comparatively light and clear, the former being better lubricating oils, the latter serving as a basis for the production of illuminating oils. In some, the solid basis is paraffin, but those of California have asphaltum for a basis. There is a resemblance between natural oils and certain oils produced from the distillation of animal remains such as menhaden oil, and between natural gas and gases produced artificially from coal, and from the decay of organic remains. Indeed, natural gas is principally composed of marsh gas. This has led to the theory that these substances are the result of natural distillation of organic remains in the rocks, and this theory is quite generally accepted by American students of the subject. It may be stated that theories have been offered to account for petroleum and natural gas by chemical reactions between inorganic substances; but, although offered by eminent chemists, the theory has little to recommend it aside from the fact that changes such as are suggested would produce petroleum. The

¹ This subject is discussed by J. F. Carll in Report III., Pennsylvania Geol. Survey, pp. 270-284.

geology of the oil fields excludes these theories. By the decay of vegetation hydrocarbons of gaseous, liquid, and solid nature result, and by a concentration of the solid and liquid products, through the loss of the gaseous hydrocarbons, petroleum is produced, and by a still further process of concentration solid paraffins or asphalts are formed. A chemical analysis of natural oils and gases would show a close resemblance to those artificially produced, but the chemistry of the hydrocarbons is so complex that little can be given in this connection. Naphtha, benzine, illuminating oils, etc., compose it.

While we must believe that these substances are derived from the decomposition of organic matter, there is an opportunity for a variety of explanations of the process by which this was brought about. Some have held that vegetable matter has produced the hydrocarbons, and others, that the source is from animal fossils; probably each and a combination of the two are correct for different fields. A study of the stratified rocks shows that certain shales and limestones are highly bituminous and that some are fetid from the odour of decayed animal remains. There are abundant reasons for the belief that petroleum has resulted from the *slow* destruction of organic remains, both animal and vegetable, during the changes through which the rocks have passed.

It has been suggested that the source of the hydrocarbons is the coal, these having been driven off, with comparative rapidity, by a process of destructive distillation analogous to the production of artificial oils and gases. Unfortunately for this theory the greatest supply of these substances comes from rocks below the horizon of the coal, and moreover the larger oil fields are in horizontal rocks which have undergone

very little metamorphism. Therefore, while it must be admitted that this is a possible source, it is not the source of the bulk of our petroleum. Destructive distillation may account for the oil in the tilted rocks of California, and for the Colorado oils, but it cannot be accepted for the fields of the east.

The distribution of oil and gas through the rocks presents many interesting features. At first they were supposed to be confined to the rocks beneath the valleys, the theory of the well-drillers being, that in some way the surface topography influenced the distribution of the petroleum; but there is of course no such association. A thorough study of the oil fields thus far explored shows that, while this substance may occur in any stratified rocks, of almost any geological age since the Cambrian, the petroleum in a single area is confined to a definite bed, whose depth from the surface and probable extent can be predicted with considerable accuracy. Taking our eastern fields as a basis, since they are so much better explored and understood, it is found that, in a single producing field, the oil occurs in more or less restricted areas or "pools," and that the pools in the Pennsylvania-New York district are more or less linear in extent, with their longer axes in general parallelism with the axes of the Appalachian folds.

In distribution and behaviour the oil has a certain resemblance to underground water. This resemblance is noticed in the tendency of these substances to accumulate in porous strata bounded, above and below, by more impervious layers. Where these strata outcrop, oil sometimes oozes out at the surface, like a spring of water. When a well is drilled into an oil-bearing stratum, the petroleum rises to the sur-

face, after the manner of an artesian well, and at times, single wells produce many thousands of barrels in a day. The resemblance ceases here, and we find that there are certain marked differences. A supply of underground water is perennial, and, year after year, an artesian well will continue to flow with unabated volume because the surface rains soak into the earth and take the place of the water which escapes. But the supply of oil is the accumulation of ages, and, when once the stratum is exhausted of its store, no more will come, excepting, perhaps, after a long period of time, when fresh supplies have been formed. Moreover, while the force of ejection of the oil is, in part no doubt, hydrostatic, as in the case of artesian wells, yet there seems abundant reason to believe that this force is in no small degree due to the expansion of contained gases.

It might, perhaps, be expected that oil would accumulate more rapidly in mountainous regions where distillation of a destructive nature is in operation, such as that which drives off the volatile substances from coal to produce anthracite. But probably this very force of metamorphism aids also in the distribution of these substances, chiefly by producing joints and fissures through which they can escape, imitating, in a natural way, the artificial process of tapping an oil pool by a drilled well. For the formation of oil accumulations the strata must usually remain practically undisturbed. Under these conditions the so-called pools are formed, this name being given because the oil is distributed unequally, as if in pools. When such an area is reached by a drilled well, gas sometimes escapes, then oil, and finally salt water; but at times this

order is reversed, or in some cases oil first flows, or all three may come at once, or only one of the three substances may come, from a single well, throughout its history. There are probably various explanations for these phenomena, and several theories have been advanced to account for them.

If the three substances are accumulated in a stratum, it is natural to expect that they will be stratified according to their specific gravity, the gas at the top and the salt water at the bottom. One of the old theories to account for the accumulation of these substances into pools or limited areas and for their irregularity of escape, is the *Cavern Theory*. This assumes that the gas, oil, and salt water have accumulated in subterranean caverns, of irregular form, and that they occur in layers, the gas at the top, then oil, and finally salt water at the bottom. If the arch of the cavern be pierced by the well, the order of flow will be gas, then oil, and finally salt water; but if one end be encountered, near the lower levels of the cavern, salt water will first escape, while oil will come first if a point a little higher up on the sloping side of the cavern be encountered. There is very little reason to believe that this theory is applicable, and good reasons for doubting its value, for it is highly improbable that such caverns exist, particularly in a bed of sandstone or conglomerate, where caverns would be difficult of formation. Moreover, the well-borings show no signs of large cavities.

Recently the *Anticlinal Theory*¹ has been brought into prominence by the rapid development of the oil fields of

¹I. C. White, *The Mannington Oilfield and the History of its Development*, Bull. Geol. Soc. Am., Vol. 3, 1892, pp. 187-216.

West Virginia, which have been opened, in part, upon the basis of predictions made in accordance with this theory. It is, briefly, that ^{*}beyond the main folds of the Appalachians the strata, on the bordering plateau at the western base of these mountains, were thrown into a series of waves or folds of slight elevation, and that the oil, furnished by the decomposition of organic remains, tending to accumulate in the porous strata, found it possible to accumulate in the highest parts of these strata; namely, in the crests of the low anticlines, while the intervening troughs or synclines were left barren, or nearly so. Gas would rise to the extreme crest, while oil and salt water would be found on the outside at a slightly lower level. This theory accounts for the general parallelism of the fields to the axes of the Appalachian folds, for their limited extent and distribution, and, indeed, for all the general features exhibited.

There can be little doubt that the anticlinal theory is proved, so far as the West Virginia fields are concerned, and also that it accounts for some of the fields in Pennsylvania; but there is good ground for doubting whether it can be extended to all of these fields. Some of the oil pools appear to be due to original irregularities of the oil-bearing stratum. These strata are of marine origin, and it is a familiar fact to be observed in all sediments from water, whether on the seashore, lake shore, or river banks, that they vary in character from place to place. Thus, on a beach the material is pebbly in one place and sandy in another, and the same stratum may be sandy near shore and clayey off shore. Moreover, the sediments deposited opposite the mouths of rivers differ from those formed in the intervening areas. Therefore a horizon, such as one of the oil-bearing sands,

may vary markedly in even a small area. Perhaps the texture varies, or possibly more iron or lime were furnished in one place than in another, and this would allow some parts of the bed to become firmly and compactly cemented, while other portions remained loose and pervious. The stratum, below or above, which furnished the oil may have varied in its ability to supply the petroleum, and in one or all of these ways there may very well have been a marked variation in either the supply or the concentration of the gas or the oil, thus causing an accumulation into limited areas, pools, or pockets, and this theory may be called the *Pocket Theory*.

The essential features of an oil pool are a source of supply and a porous stratum bounded above and below by more impervious strata. The source is some neighbouring layer rich in organic remains, and the porous stratum acts as a reservoir. The exact mode of accumulation may vary, the organic material being changed to oil and gas by a process of slow distillation, and gathered into the reservoir, which may be a porous pocket in an irregularly porous stratum, or else in the crests of low anticlines. This has been written with especial reference to the Appalachian oil fields; but, while the general remarks hold for some other fields, they cannot be extended to those of California. There, however, as probably also in all other oil fields, the source of supply is organic remains, although the exact mode of accumulation is different.

Uses of Petroleum.—The remarkable growth of the kerosene oil trade, as the result of the discovery of our large stores of petroleum, is a matter of history with which we are all familiar. In 1892, 54,291,980 barrels (of 42 gallons) of

crude petroleum were produced in this country, and of this, 36,545,634 barrels were used in the manufacture of illuminating oil, while 17,676,212 barrels were used as fuel oil, and 70,134 barrels for lubricating purposes. Wonderfully expensive methods of piping are employed for the transportation of this oil to distant points and also for its reduction; but because of the great scale upon which these operations are conducted, these methods are economical. This has created an industry in which the United States holds almost a unique position. Not only is our home demand fully supplied, but the products of the petroleum industry find their way into nearly all the markets of the world. In 1891, 531,445,099 gallons of illuminating oils, valued at \$34,879,759, were exported from this country, and over \$11,000,000 worth of other products made from petroleum were also exported.

Aside from the production of illuminating and lubricating oils, the product of some districts is used chiefly for local fuel. During the reduction of petroleum to illuminating oils, naphtha, benzine, and gasoline are formed; and a solid residuum of the paraffin series, used in the manufacture of vaseline and other similar materials, is also produced. All of these substances are manufactured for export as well as for the home market. Petroleum must be classed with coal and iron as one of the most important mineral products of the country and one which has added largely not only to our industrial progress, but also to the comforts of living.

Production of Petroleum.—Statistics for the production of petroleum in foreign countries are difficult to obtain, but the following tables show the distribution of the output in this country, and, in a very general and incomplete manner, in the foreign nations:—

PRODUCTION OF PETROLEUM IN THE UNITED STATES

BARRELS (42 GALLONS)

STATES	1860	1870	1876	1880	1885	1888	1890	1892
Pennsylvania and New York	00 000	5 200 74	8 000 900	26 000 000	20 770 041	10 158 068	28 408 205	32 080 000
Ohio			31 76	38 240	0 0 000	10 010 848	10 124 681	20 000 000
West Virginia			120 000	170 000	91 000	119 448	11 775	1 000 000
Colorado						297 012	368 842	700 000
California			12 000	40 000	3 000 000	630 333	307 300	185 000
Indiana							63 496	70 000
Total for the United States	00 000	50 74	8 113 000	26 040 000	20 774 041	10 158 068	39 222 672	54 344 700

In 1859, which was the first year of petroleum production, 2000 barrels were produced, and, from this time till the close of 1862, it is believed that fully 10,000,000 barrels of oil ran to waste in the Pennsylvania field, because there was no market for it. From 1859 to 1882, the output of Pennsylvania increased rapidly, the production in the latter year amounting to 30,053,500 barrels. There was then a period of exhaustion of old wells and a failure to open extensive new fields, which culminated in the very low production of 1888. Since then the discovery of new pools has caused a marked increase in the output, until, in 1891, the highest output ever reached, over 34,000,000 barrels, is recorded. Very nearly the same variations appear in the table of total output, since, until 1887, the production of the country was practically that of the Pennsylvania-New York field. The remarkable increase of output since 1887 is attributable, in large measure, to the development of the Ohio fields and the discovery of the new pools in Pennsylvania, although

the other oil-producing states have helped this increase slightly.

At the close of 1891 the United States had produced, since the opening of the first well, 508,447,362 barrels of crude petroleum, of which 429,755,990 barrels, or 84.5 per cent of the total, came from the Pennsylvania-New York fields, and 64,377,499 barrels, or 12.7 per cent, from Ohio, these three states together having produced 97.2 per cent of the output of the country. In 1891, the Pennsylvania-New York field supplied 60.8 per cent; Ohio, 32.7 per cent; and West Virginia, 4.4 per cent, of the total output of the country.

PRODUCTION OF PETROLEUM IN THE WORLD.

METRIC TONS (2204 LBS.).

COUNTRIES.	1889.	1890.	1891.
United States . . .	4,925,647	6,418,765	7,595,702
Russia	3,306,814	3,974,531	4,000,000 ²
Germany	9,519	15,226	15,315
Peru	2,151	2,324	....
Canada ¹	639,991	765,025	755,295
Italy	177	417	1,155
Japan ¹ . . . . .	....	48,027	...

The value of the crude petroleum produced in the United States in 1892 was \$30,229,128.

Natural Gas.

General Statement.—In general, the description of petroleum applies to natural gas. It belongs to the group of

¹ Barrels.

² Estimated.

hydrocarbons and is a member of the paraffin series. Marsh gas constitutes from 50 to 90 per cent of the Pennsylvania gas, and with this there is nitrogen, carbonic dioxide, and some other gases. The following analyses will give an idea of the chemical composition of some of the natural gases:—

ANALYSES OF NATURAL GAS.

	KINDLAY, OHIO	FOSTORIA OHIO	SAINT MARY'S, OHIO	STOCKTON, ¹ CALIFORNIA	PENNSYLVANIA
Hydrogen	1 64	1 89	1 74	0 06	Very little
Marsh gas	93 35	92 54	93 45	83 00	Paraffins, 84 26-97 7
Olefiant gas	0 35	0 20	0 20		
Carbonic dioxide	0 41	0 55	0 44	0 05	Less than 1 per cent
Carbonic acid	0 25	0 20	0 23		
Oxygen	0 39	0 35	0 35	0 06	Trace
Nitrogen	3 41	3 82	2 98		2-15
Sulphuretted hydrogen	0 20	0 15	0 21		Trace

The geological distribution of natural gas very closely resembles that of petroleum, it being widely distributed through the strata from the early Palæozoic to the present. Marsh gas, which is very similar to this, is being formed at present in swamps by the decay of vegetation. In Pennsylvania the natural gas is found chiefly in the Upper Carboniferous, in Ohio in the Trenton limestone, and more rarely and less abundantly in local reservoirs in the drift. As in the case of petroleum, a porous rock, with impervious enclosing strata, is the common reservoir, and the reason for this is the same in both cases. There is also a frequent association of gas with low anticlinal crests; and, while it is frequently found

¹ Incomplete.

free from association with petroleum, this association is not uncommon. Natural gas has been found in nearly all the states and territories, but the most important sources are western Pennsylvania and New York, northwestern Ohio, and eastern central Indiana. The origin of this gas is the same as that of petroleum, the one being a gaseous, the other a liquid, representative of the paraffin series of which paraffin wax is the best known illustration of the solid form.

Natural gas was known to exist in the very earliest days of the exploration of western New York, where it escaped from crevices in the rock. In 1821 a well was drilled at Fredonia, Chautauqua County, New York, and gas for lighting purposes was obtained. Other wells were found later, in the same region, and in 1841 natural gas, which had long been known to exist in Virginia, was introduced into the manufacture of salt for purposes of evaporation. Gas was also found to exist in association with the salt in salt wells, but the most important development of the gas fields has come since the discovery of petroleum in 1859. The extensive drilling for oil, which has been carried on all over the Union, has succeeded in developing gas fields, not only in association with petroleum, but also in regions where this substance is not found. Since 1880 gas has become an important factor in and near the oil fields.

Aside from the sources of this substance above mentioned (Pennsylvania, Indiana, Ohio, and New York), some is also produced in Kentucky, West Virginia, California, and, in still smaller quantities, in other states. Outside of the first four states there are very few uses for natural gas, and the industry of its production is therefore not as well developed as the quantity of this substance would seem to warrant. The

Ohio field has been found to extend into Ontario, and considerable is produced in this province. In China, also, wells have been bored, and large stores found, and natural gas has been discovered in other places; but there is more of this substance in the United States than in any other country in the world.

When gas is first found, it issues from the wells with tremendous force, under the pressure of the strata and of its own compression. Four wells in the Findlay gas region each produced over 1,000,000 cubic feet per day, and one, the Karg well, produced, at first, over 12,000,000 cubic feet per day. Some wells have had a pressure of 800 pounds to the square inch, and many have a pressure of from 400 to 500 pounds. The Findlay wells, when first found, in 1885, had a pressure of 450 pounds to the square inch, in 1886, 400 pounds, in 1889, 250 pounds, and in 1890 as low as 170 pounds to the square inch. These figures show that the gas wells are by no means permanent. Since 1888 the pressure, and consequently the output, of the great wells has been decreasing, and some which at first seemed inexhaustible are rapidly approaching the end of their productive days. The companies producing gas have recognized the probable fate of the industry, and are applying much more economical methods of using and distributing it. Already the natural pressure has been supplemented in some wells, by pumping, and, where this has been introduced, it will continue the gas supply a little longer; but, in general, it is a last resort employed in a nearly exhausted well. This failure of supply is exactly what was predicted by those whose studies of the gas and oil fields forced them to the conclusion that these substances were simply stored in the rocks, and not continuously supplied, as some well-owners believed.

Uses of Natural Gas. — When first found, the natural gas was of very little use, and immense quantities were allowed to escape. Its value soon became recognized, however, and efforts were made to introduce it for fuel and for illuminating purposes. This is still practically the only use of gas, although it is also used in the preparation of lampblack for the manufacture of the carbon-points for electric arc lamps. Aside from the latter use natural gas is of importance only locally, and this is the first substance discussed of which this is true. It cannot be exported, nor can it be conducted to any great distance from the wells.

As a fuel, natural gas is used for heating and cooking, in the manufacture of iron and steel, for glass manufacturing, and, indeed, for scores of purposes where cheap fuel is needed. Gas has been so successfully introduced for these purposes, in the region near its source, that especially prepared burners are introduced, and very little waste is now experienced; but, with the approaching exhaustion of the wells, serious problems are about to be presented; and, indeed, already some of the companies are refusing to supply large manufactories with this fuel. Probably new fields will be discovered, but it is hardly likely that in the old regions many important new ones will be found. Little by little the industry must fail; for, unlike most industries, this is dependent entirely upon local and comparatively limited supplies; and, while an iron foundry, by the transportation of iron from other fields, might survive the exhaustion of neighbouring iron mines, this is not possible in the gas industry.

The following table shows the various uses for which gas was employed in 1889: —

CONSUMPTION OF NATURAL GAS IN THE UNITED STATES, 1889.

CUBIC FEET.

Various industrial establishments: brick and pottery burning, electric plants, machine shops, foundries, etc., 2360 establishments in all . .		236,900,000
Iron and steel mills		171,500,000
Heating and cooking		62,500,000
Drilling and operating oil and gas wells		30,000,000
Miscellaneous uses		25,000,000
Glass works		18,750,000
Pumping oil		7,500,000
Total		552,150,000

Production of Natural Gas.—There is very little basis for an exact estimate of the production of this substance, since so much is wasted, and so many different ways are made use of, by the various companies, for measuring their production. The current method of estimating the natural gas output is to state the value of the coal which it has displaced; but this sometimes underestimates and sometimes overestimates the value of the production. The following tables are based upon this method of estimate, combined with the known amount received by some of the companies:—

PRODUCTION OF NATURAL GAS IN THE UNITED STATES.

STATES.	1885.	1887.	1888.	1889.	1891.
Pennsylvania . .	\$4,500,000	\$18,749,500	\$19,282,875	\$11,598,989	\$7,884,016
Indiana . . . .	....	600,000	1,320,000	2,075,702	3,942,500
Ohio	100,000	1,000,000	1,500,000	5,215,669	3,076,325
New York . . .	196,000	333,000	332,500	580,026	280,000
Kentucky . . .	....	....	....	2,580	88,998
West Virginia . .	50,000	120,000	120,000	12,000	85,000

In 1889, Pennsylvania produced over one-half of the supply of the country, Indiana about one-fourth, and Ohio nearly one-fifth; or the three states together about nineteen-twentieths of the supply of the country. The rapid increase in Pennsylvania's output, which reached a maximum of over \$19,000,000 in 1888, followed by a rapid decline, is a noteworthy feature of the table. Ohio has also rapidly increased its output, and this has been followed by a decline, while the Indiana output has gradually increased.

NATURAL GAS PRODUCTION OF THE UNITED STATES.

1882	\$215,000
1883	475,000
1884	1,460,000
1885	4,857,200
1886	10,012,000
1887	15,817,500
1888	22,629,875
1889	21,097,099
1890	18,742,725
1891	15,500,084
1892	13,000,000

Before 1882 much gas was produced, but it was practically all wasted. The wonderful increase from 1882 to 1888 and then the continuous and rapid decrease to the present time are very striking features of the table, and these variations are primarily due to Pennsylvania. The value of the natural gas produced in Canada, in 1892, was \$160,000.

Asphaltum.

Certain semi-solid bitumens, varying slightly in character, and to which different mineralogical names¹ are given, are

¹ The names of the various varieties are albertite, asphaltum, brea, elaterite, gilsonite, grahamite, lithocarbon, maltha, uintite, and wurtzilite.

included under the general term of asphaltum. In this country, as in many others, bituminous shales and limestones with very small percentages of bitumen are not uncommon, and some of them are sufficiently bituminous to be employed directly, in place of prepared asphalt,¹ while others are used as a source of asphalt. Bituminous sandstone is quarried extensively in Kentucky and California, while in Utah a bituminous limestone is used for a source of asphalt; and in this territory there is also found a variety known as gilsonite. Recently an extensive deposit, which is called litho-carbon, has been discovered in western Texas, but as yet there has been no output. Other deposits are known to exist elsewhere in this country, but at present they are of little importance. The chief supply of the asphalt used in the United States comes from the island of Trinidad, where the famous pitch lake occurs; but other regions, notably Sicily, also produce asphaltum.

The origin of this substance is, in some places at least, from organic remains, by a slow process of distillation similar to that which produces petroleum. In the bituminous limestones and shales, bitumen, instead of petroleum, has resulted by the concentration of the solid parts and the dissipation of the volatile portions. This has resulted, in the sedimentary strata, from slow distillation; but, in the neighbourhood of igneous rocks, it may have been caused by destructive distillation. The resemblance between this mineral and petroleum is shown by the fact that in the California petroleum the solid base is a form of asphaltum. It has been suggested that the stages of change are first the transformation of

¹ The term *asphaltum* is given to the unfinished product, and *asphalt* is the commercial name for the finished product used in street-paving.

organic remains to oil, then to asphaltum, next to jet, and, finally, under sufficient metamorphism of the proper nature, to diamond. While this is purely hypothetical, it is not improbable. The chemical composition is closely like that of parts of some petroleums, and the California petroleum has asphaltum for a base. Products closely resembling asphaltum can be produced artificially.

This substance is employed, in the form of asphalt, for paving streets, and this is by far its most important use; but it is also made use of as a varnish for coating piles and wharf timbers.

PRODUCTION OF ASPHALTUM IN THE UNITED STATES.

Year.	Short Tons.	Value.
1880.	444	\$4,440
1885.	3,000	10,500
1890.	40,841	190,416
1892.	54,985	291,250

Owing to the cost of transportation, the greater part of the asphaltum produced in the United States cannot compete with that shipped from Trinidad and elsewhere, and our supply is consequently used chiefly near the point of production. In 1892, while we produced 54,985 tons, our imports amounted to 109,582 tons, the greater part of which came from Trinidad.

Ozokerite.

A mineral belonging to this series is mineral wax or ozokerite (ozocerite), which occurs in Galicia, in Austria-Hungary, but which has also been found near Thistle in Utah. It is a yellow mineral, grading to a dark brown,

sometimes greenish, and varies in hardness from very soft to the hardness of gypsum. It may be considered an altered form of a petroleum, robbed of its volatile substance, and more nearly resembling that of Pennsylvania than that of California. It is chiefly a solid paraffin with some benzine, naphtha, etc. The uses of this mineral are, as a substitute for beeswax, in the manufacture of candles, for purposes in which vaseline is employed, and as an insulator in electricity. Before 1888, when ozokerite was discovered in Utah, Galicia was the source of this mineral, which was first obtained there in 1862. Our product, in 1892, was 130,000 pounds, valued at \$7800, while we imported 1,250,000 pounds. The industry of mineral wax production is slowly increasing.

CHAPTER XVI.

BUILDING-STONES AND CEMENTS.

*Building-Stones.*¹

General Statement. — The non-metallic structural materials may be divided into four groups, — building-stones, ornamental stones, natural and artificial cements, and clays. All but the last of these are included in this chapter, the clays being omitted here, since a very important use for these substances is the manufacture of pottery and ornamental ware. Gypsum, which is also used for structural purposes, is omitted here, but is considered under fertilizers, since this is one of the most important uses of the mineral. Under building-stones is included the limestone burned and used for fertilizing purposes, and that, also, which is burned for lime to be used in plaster. For the term *building-stones* a more comprehensive word might be substituted, since under this heading is included, not only the stones used for building, but those also quarried for other structural purposes, such as pavements, fences, bridges, monuments, etc.; but, although this is perhaps a poorly chosen term, it is employed here because it is in common use in the statistical works.

Practically, none of these products are of value for export.

¹ The general subject of building-stones is treated by Merrill in his *Stones for Building and Decoration*, New York, 1891; and, in this connection, Burnham's *Limestone and Marble* will be found of value. The Tenth Census volume on *Building-stone* is also of value.

tation, but nearly every country, and, in our own country, nearly every section, produces its own supply. Thus, in regions of granitic rocks, granites are commonly used, while in sandstone regions, buildings and other structures are more commonly made of this stone than of any others. Only the very finest quality of stone is capable of profitable transportation, and hence we neither export nor import any but the best, usually ornamental stone. Where particular kinds and colours of marble are desired for interior decoration, or certain granites or marbles are needed for monuments, these are imported in some cases; but the amount of these importations is very small, being greater for marble than for any other stone. Even within the country there is a very small amount of distant transportation. Certain colours of stone, needed for trimming, may be carried long distances where a particularly beautiful building is to be constructed; and where cheap transportation by water is possible, even paving-blocks may be carried several hundred miles; but, notwithstanding these exceptions, the industry of building-stone production is essentially a local one. If statistics were obtainable of the distribution of the stone product which is actually sold, this would be found to be very marked, but not nearly so striking as it really is, since large quantities of stone used for structural purposes are never put upon the market, but are quarried by the consumers. For this very reason the statistics of building-stone production, as given below, are far below the actual value of the industry.

Granite.—Under the term *granite*, as used in the trade, is included a great variety of igneous and metamorphic rocks, among which are the true granites; and these, it is true, form the greater part of the so-called granites. Normal

granite, using the term in its strict scientific sense, is an igneous rock intruded at considerable depth into the earth, hence a plutonic rock, having a coarsely crystalline structure and being made up of a granular, interlocking series of quartz, orthoclase, feldspar, and grains of either hornblende or mica (usually biotite), sometimes both. Other minerals are present, usually in minor quantities, and as accessories. The coarseness of texture varies greatly from an extremely fine grain to a very coarse rock; and, indeed, some granites are entirely too coarse for use. The colour is also extremely variable, some being almost white, others a very dark green, some blue, and some red. These colours depend in certain cases on the proportion of the constituent minerals, but most commonly upon a pigment contained in the feldspars. Even in the same rock some of the feldspars are red, while others are white, and just what these pigments are is not always easy of determination. It is sometimes minute grains of iron and often a series of microscopic inclusions of some coloured mineral.

Different kinds of granite are used for different purposes. For monuments and ornamental work there is an especial demand for coloured granite, generally of fine grain, which fits it for polishing; but in many of the uses for which granite is employed the colour is of minor importance, durability, hardness, and cheapness (the latter depending upon the ease of working it) being of prime importance. This stone occurs in large masses almost entirely in the older rocks, and very commonly in the metamorphic series. This is one reason why New England is of so much importance in the production of granite; but it is also necessary that the rock shall be so situated that it can be easily quarried and transported at a

slight cost to a good and permanent market. Thus it is that so many quarries are situated on or near the seashore where water transportation is possible.

Another important feature in granite is to have its texture and colour moderately uniform, and many very beautiful stones are rendered of little value, for most purposes, by reason of frequent inclusions or bunches of darker coloured minerals, which give to the rock a blotched surface. These bunches are, in some cases, actual inclusions of some other rock torn off from the country rock, when the granite was forced in a molten condition through the strata into its present position. These are partly melted and merged into the granite, but the centre is frequently very little changed and forms a marked contrast to the stone. Even more common than these are the dark bunches known as basic secretions, which are accumulations of the darker minerals of the rock into bunches by a process analogous to concretion, which operates while the rock is cooling from the igneous condition. Thus, hornblende, biotite, magnetite, and other basic minerals, gather together into bunches which are frequently so abundant that it is impossible to obtain a slab which is free from them. In some granites, particularly the coloured and darker kinds, these are very abundant, while in the lighter granites they are often nearly absent; and even in the same quarry there is considerable variation in the abundance of these patches.

Granite is an extremely hard and durable rock. The quartz which it contains, although brittle, and thus affecting its crushing strength, is practically indestructible, and feldspar normally weathers slowly and does not seriously injure the rock. It is also nearly as hard as quartz and

PLATE II.—Rockport Granite Quarry, Rockport, Massachusetts. Showing method of quarrying granite. Dark surfaces are joint planes. Horizontal cuts are indistinctly seen. The pit is shown in the left-hand corner by the smooth fracture faces.



somewhat less brittle. The weakest parts of the stone are the basic minerals, chiefly the biotite, hornblende, and magnetite, which are generally in less abundance than either the quartz or feldspar. Under the influence of the weather these begin to decay to other minerals, of which the oxides of iron are the most prominent. It is this which causes the red stain or rust upon joint planes, sometimes extending into the rock for a distance of several inches. Quarrymen call this the "sap," as if it were rising from the granite and passing out, while in reality it begins at the surface of the joints and slowly extends inward as fast as the percolating water can effect the necessary changes in the minerals. At first this does not materially weaken the rock, although it soon combines with other changes, particularly the kaolinization of the feldspar, and causes the granite to crumble. For a long time this "sap" stain was believed to ruin the stone, but recently it has been introduced into buildings; and, when the main part of the structure is composed of this rusted rock, trimmed with a lighter coloured stone, a very beautiful building is constructed. Instead of being thrown away, as it has been in the past, this rusted granite, because it is comparatively scarce, promises soon to become one of the most valuable products of the granite quarry.

This rock is so hard that but for the presence of planes of mechanical weakness it could not be utilized for many purposes for which it is now so valuable. These planes are of two kinds,—joint planes and microscopic planes (rift), along which the rock tends to split. There are ordinarily four sets of joint planes in a granite quarry (Plate II.). One of these is a nearly horizontal jointing, which sometimes assumes an angle of 15° or 20° , and is the result of

the contraction of the rock during cooling. By this set of joints the granite is traversed at various intervals, the divisional planes forming dome-shaped blocks with a radius of many yards, sometimes of several hundred feet. In some quarries the joints of cooling are so numerous that large blocks cannot be extracted; but in others, where the horizontal joints are several yards apart, it is possible to obtain immense blocks of the granite. The other three sets are nearly vertical, two of them meeting at an angle approaching a right angle, while the third cuts diagonally the rhomboidal blocks thus formed. These are joint planes, partly of contraction, partly of mechanical origin, the result of folding and crushing of the granite during subsequent movements of the rocks. As in the case of the nearly horizontal joints, there is great variety in the number of the planes of breakage, and while sometimes they are twenty, thirty, or even as much as fifty feet apart, in other places they cut the rock in such numbers that it breaks into small pieces, a veritable fault breccia, which ruins the granite for economic purposes.

These joint planes are of great importance in quarrying, since they form bounding planes, beyond which the charge of powder used in blasting will not break the rock. A series of smooth, naturally-formed working faces are thus furnished, and the work of quarrying greatly facilitated. Near the surface the joint planes furnish channels for the passage of underground water; and it is for this reason that their faces, and the granite for some distance in from these, are discoloured by iron rust; but as the depth of the quarry increases, the joint planes become less numerous. This shows that the joints are, in some cases at least, merely

microscopic planes of splitting developed by percolating water. The green seams which are present in many quarries illustrate this still better. These are joints, along which some chloritic minerals have accumulated, and which are called blind seams by the quarrymen when the chloritic minerals are absent or not present in sufficient abundance to be indicated on the surface of the freshly quarried rock. Even after the block has been blasted from the quarry, these seams may not be visible, and sometimes, during the final shaping of the stone, it splits along one of these invisible planes, and causes the loss of all the labour employed. This is not a very common occurrence, but it is interesting for the purpose of showing what joint planes probably are.

Even more important than the joints are the microscopic planes of weakness known by quarrymen as "rift."¹ Examined with the microscope, these are shown to be microscopic breaks and tiny faults crossing all the minerals, but usually not with sufficient development to injure the strength of the rock. In well-rifted granites these planes of breakage can be seen with the naked eye; but at times they are shown only when the rock is split, by a tendency to a smooth fracture in certain directions. There are three sets of smooth-fracture planes in some quarries, the most pronounced vertical plane being called the "rift"; the second, the "cut-off"; and the third, a horizontal plane, the "lift." One of the first things to be determined in opening a quarry

¹ The remarks upon rift are based upon a study of the granite in the quarries at Cape Ann, Massachusetts. So far as is known, studies of this phenomenon similar to those made by the author have not been carried on elsewhere, although rift is common in granite.

is the direction of these planes, and in drilling holes for splitting the rock these directions are followed. The rift furnishes the direction for the greatest length of the block, the cut-off for the least important end, and the lift for cleaving the block upon the third side. When these planes are well developed, large blocks twenty or twenty-five feet square, and even more, are readily split from the quarry, with such smooth faces that very little dressing is needed to prepare the rock for polishing. In no class of work is this tendency of splitting so needful as in the preparation of paving-blocks, the cheapness of which depends upon the facility of breaking in three directions.

Aside from granite proper, many other igneous and some metamorphic rocks are used as granite, and called by this name in the market. One of these is gneiss, a metamorphic rock, which, in some cases, so closely resembles a granite that only a careful study serves to distinguish it. This rock, however, frequently has a lower crushing power than granite, because of the presence of the gneissic structure, which is a direction of weakness, often very marked. One of the principal objections to gneiss is the lack of uniformity of texture and colour, which, excepting in unusual cases, is not so good as in ordinary granites. Much gneiss, however, which is quarried and sold as granite is a really good stone which cannot be distinguished from a good granite by the ordinary characters of economic importance. Very nearly every igneous rock is quarried and sold as granite,¹ and some of them are not seriously inferior to true granite. Syenites, in which there is no quartz, are not as strong chemically, as true

¹ Upon pages 598, 599, Eleventh Census volume on *Mineral Industries*, will be found, tabulated, the various varieties of rock sold as granite.

granites; but they are of better quality than many of the igneous rocks. The basic rocks, such as diabase and diorite, contain minerals which decay so readily that they are generally unfit for exposed work. By far the greater part of the rock quarried and sold as granite is normal granite; but since so much that is not of this species is sold under this name, one should, before using any other kind, carefully study the character of the rock, provided a use is to be made of it which requires durability and strength.

Granite is employed for a variety of purposes; and its value varies greatly, according to the use to which it is to be put and the location of the quarry. In 1889 the total value of the granite produced in the United States was as follows:—

VALUE OF THE GRANITE PRODUCED IN THE UNITED
STATES, 1889.

Building purposes	\$6,166,034
Street work	4,456,891
Cemetery, monumental, and decorative purposes,	2,571,911
Bridge, dam, and railroad work	1,238,401
Miscellaneous uses	230,856
Total value	<hr/> \$14,464,095

This represents a total of 62,287,156 cubic feet of granite actually sold, but makes no allowance for a not inconsiderable amount quarried and used by private individuals and corporations, but not placed upon the market. Large quantities of granite are wasted in the course of quarrying and dressing operations.

PRODUCTION OF GRANITE IN THE UNITED STATES.

STATES.	1880.	1889.	1891.
Massachusetts	\$1,329,315	\$2,503,503	\$2,600,000
Maine	1,175,286	2,225,839	2,200,000
California	172,450	1,329,018	1,300,000
Connecticut	407,225	1,061,202	1,167,000
Georgia	64,480	752,481	790,000
New Hampshire	303,066	727,531	750,000
Rhode Island	623,000	931,216	750,000
Vermont	59,675	581,870	700,000
Pennsylvania	211,454	623,252	575,000
Total for the United States .	\$5,188,998	\$14,464,095	\$13,867,000

In 1891 nine states, Maryland, Wisconsin, Colorado, Missouri, New Jersey, Virginia, New York, Delaware, and South Dakota, named in the order of their importance, produced more than \$100,000, and less than \$500,000, worth of granite. It will be noticed that all the New England states are included in the first eight granite-producing states of the Union, this being the first economic product in which any one of them has held a high rank. During the year 1891, \$8,167,000 of the total output of the country came from these states. Nearly the entire supply came from the eastern states, and the greater part of this from the states of the extreme east. The rapid development of the granite industry is shown in the table, but in the last year a considerable decline is noticed. Particularly striking is the development of the industry in Georgia, Vermont, California, and Connecticut.

Sandstone. — Sandstone, being a sedimentary rock, will naturally be found where sedimentary strata abound; and in our country these conditions are most markedly developed in the central states. None is found in the metamorphic region, excepting in isolated basins, where later rocks have accumulated, as in Connecticut. Very little is produced in the Cordilleras, but less because of its absence than by reason of the difficulty of finding a market for it.

The geological age is very variable, and sandstones are found in all sedimentary strata from the Cambrian to the Tertiary; but the greater part of our supply comes from the Palæozoic in the central states and the Triassic in Pennsylvania (in part), New Jersey, and Connecticut.

The rock is composed of grains of sand, usually of quartz sand, with some feldspar, mica, etc., cemented, sometimes by silica, but more commonly by iron or by carbonate of lime. It is, therefore, a very good building-stone, provided the grains are firmly cemented. Usually the crushing power is not great; but owing to the abundance of quartz, the chemical durability is very marked. If the cement is silica, the rock is as durable as any common rock can be; but such sandstones, or quartzites, are not commonly used, because of the difficulty of quarrying and dressing so hard a rock. With a firm lime or iron cement the stone is sufficiently durable for ordinary purposes; but even in such cases, and much more markedly when the cement is not firm, water dissolves the cement, and forms crevices, which heat and frost expand, causing the grains of sand to fall apart and the stone to crumble. The effect of weathering is very well shown in many old buildings made of sandstone; but there are such buildings, many centuries old, which are sufficiently well

preserved for use at present. It is not as durable as good granite, but is one of the best building-stones.

In the texture there is great variability, though this is not as marked as in granite; for, when the grain is coarse, the rock is a conglomerate, and, ordinarily, this stone is not suited for building purposes. From this extreme, sandstones grade to a very fine-grained rock; and some of these are almost clay rocks, being, properly speaking, argillaceous sandstones. The colour is also variable: blue or green, in shades of varying intensity, as well as red, pink, brown, and white being the most common; but in the sandstones there is an almost infinite variety of colouring. According to the localities from which the stone is obtained, and frequently to the colour or texture, various commercial names are employed, such as blue or buff Amherst (Ohio) sandstone; Portland (Connecticut) brownstone; freestone, a name given to sandstones which may split easily or freely in various directions; Berea (Ohio) grit, etc.

The method of quarrying sandstone varies greatly, according to the locality and character of the stone; but, in all cases, the fact that it is a sedimentary rock aids the quarrying, by giving one direction of easy splitting parallel to the bedding. Where the strata are thick bedded, that is, with the parting planes of stratification far apart, it is often possible to obtain large blocks; but in this case the quarrying operations are more difficult, and blasting is resorted to for the purpose of breaking the rock across the bedding. In thin-bedded sandstones channelling-machines are employed to cut from layer to layer, and, in some of the Connecticut brownstone quarries, the rock is grooved with pickaxes, and then split by driving wedges at intervals in the grooves; but

this is possible only when the rock is soft. In all quarrying operations vertical joint planes are of great service, and this is true of sandstones as well as of other rocks. These joints prevail throughout all strata, although they are sometimes absent.

The value of sandstone varies greatly with the colour, texture, and the demand for particular kinds. During the census year 1889, 71,571,054 cubic feet of sandstone were quarried and sold for the following purposes:—

VALUE OF THE SANDSTONE PRODUCED IN THE UNITED STATES, 1889.

Building purposes	\$7,121,942
Street work	1,832,822
Bridge, dam, and railroad work . .	1,021,920
Abrasive purposes	580,229
Miscellaneous	259,144
Total for all purposes	\$10,816,057

PRODUCTION OF SANDSTONE IN THE UNITED STATES.

STATES.	1880.	1889.	1891.
Ohio	\$1,871,924	\$3,046,656	\$3,200,000
Colorado	9,000	1,224,098	750,000
Connecticut	680,200	920,061	750,000
Pennsylvania	627,943	1,609,159	750,000
New York	724,556	702,419	500,000
Total for the United States .	\$4,780,391	\$10,816,057	\$8,700,000

The bluestone industry is included in the statistics for 1880 and 1891. A marked increase is noticed in the produc-

tion of the country and of some of the states, notably Colorado and Ohio, between 1880 and 1889, and a marked decline, from 1889 to 1891, in the production of all the states, excepting Ohio, which is pre-eminently the sandstone-producing state of the Union. Seven states, Wisconsin, Massachusetts, New Jersey, Minnesota, Michigan, California, and Missouri, named in the order of their importance, produced between \$100,000 and \$500,000 worth of sandstone in 1891.

Bluestone. — A very fine-grained variety of shaly sandstone, usually of a bluish colour, and consisting of particles of silica and some argillaceous matter, cemented by silica, is included under this heading. Ordinarily in statistical studies this rock is included under the sandstones; but in the Eleventh Census report it is given a separate consideration, because the rock differs from sandstone both in character and use. The stone, which is intermediate between a shale and a sandstone, might, with propriety, be called a siliceous shale. Its colour is usually a dark blue, but sometimes it is light blue, sometimes green, and, in some cases, even brown. The value of the stone depends upon its fine texture and hardness, in part, but chiefly upon its thin-bedded nature, which allows it to be obtained in thin slabs suitable for flagging. This is its principal use, although it is being introduced for other purposes where thin slabs are needed. In the bluestone flags there are frequently preserved most excellent ripple marks, which prove that when it was formed, shore-line conditions prevailed at the point of deposition.

New York is the principal bluestone-producing state, and it is found there in several counties, chiefly in the central

part of the state. Both Pennsylvania and New Jersey also produce flagstones of this type. The following table shows the value of the industry, but does not give returns from a large number of small quarries, which produce small quantities of flagging for local purposes. Many of these quarries are opened by farmers, and worked at intervals when farming work is not pressing.

PRODUCTION OF BLUESTONE IN 1889.

New York	\$1,303,321
Pennsylvania	377,735
New Jersey	8,550
Total	<hr/> \$1,689,606

Slate.—This rock is formed by the alteration of clay strata, of sedimentary origin, and the slaty cleavage is a new structure imposed by pressure and metamorphism, which have sometimes operated even to the extent of destroying the original bedding. The new structure, which is called slaty cleavage, is developed at right angles to the direction of the pressure, and consists in the formation of new minerals, chiefly hydrous and other micas, which give to it the shiny surface of the slate faces and the ease of splitting in a given direction, parallel to the faces of the mica plates, and dependent upon the general parallelism of these plates. It is an intermediate stage between clay rocks (such as shales) and mica schist. The sedimentary origin of the rock is sometimes shown by the presence of bedding planes, usually at an angle with the cleavage, and more rarely by the presence of distorted fossils. In colour the slate is usually slate-blue; but there are green, brown, purple, and red

slates. These shades depend upon the prevailing colour of the component minerals or upon some stain or pigment, the red and brown being due to iron, the purple to mangiferous minerals, the green to chlorite, and the blue to a combination of chlorite, carbonaceous matter, and other substances.

Slates may be of any age where metamorphism has altered clay rocks to the stage of slates. They are almost universally absent from the Archean, because, if clay rocks ever existed there, they have passed the slate stage of metamorphism and become mica schists. These rocks are usually absent from the strata of post-Palæozoic age, for the reason that rocks of this age have not usually been exposed to extensive metamorphism. Still, in California the strata of the Sierra Nevada consist in part of slates of Cretaceous age, and there are more recent slates elsewhere. The Palæozoic age, and of this the earliest members, is the most important slate-bearing series both in this country and elsewhere. This rock is widely distributed, but the most important states are situated in the Appalachian and New England regions, where there is a belt of Cambrian and Silurian age, extending from Vermont to Georgia.

The value of slate depends upon the presence of the remarkable cleavage which admits of its being split readily in a single direction so that thin sheets of moderate size can be obtained. In quarrying slate, joint planes are of great importance; but when they are too numerous, the rock splits into such small blocks that slate for tiling cannot be extracted. While this rock is extremely common, good roofing-slate is comparatively rare, because either the texture is not uniform, or the colour not suitable, or the cleavage not

properly developed, or joint planes too numerous. Many slates, called argillites, have not had the slaty cleavage developed to a marked degree, either because of the original texture, or the fact that metamorphism has not been sufficiently powerful. On the other hand, some slates have such a shaly structure that the flakes are too thin for use; others have several cleavages, which cause the rocks to split with an irregular surface; and in some the bedding is not sufficiently destroyed to prevent its furnishing a second plane of cleavage. A good roofing-slate must be massive and strong, with only one cleavage, which must be well developed; and it should have a uniform texture, a permanent colour, and should not be too brittle for cutting into regular forms. While the greater part of the slate is dark blue, the light blue, green, red, and other colours are used for figures, margins, and, in general, for relieving the monotony of a single colour in roofing.

By far the greater part of the supply is used for roofing, but some is also consumed in the manufacture of slates for school purposes, for strips, flagging, sills, mantels, wash-bowls, and many minor purposes, where an easily worked rock of uniform texture and colour is desired. Marbled stone, which is being introduced for interior work, in imitation of banded and coloured marble, is made by a process of graining with colours upon slate tablets and slabs. Some of this work is very beautiful, but the fact that it is an imitation, and not permanent, is liable to prevent its general introduction. The rapidly increasing use of metal for roofing is interfering with the consumption of slate for this purpose, particularly in the east. In 1891 the total consumption of slate was valued at \$3,825,746, of which \$3,125,410 worth

was used for roofing purposes, this amount representing 893,312 squares of slate.

PRODUCTION OF SLATE IN THE UNITED STATES.

STATES.	1880.	1889.	1891.
Pennsylvania	\$863,877	\$2,011,726	\$2,141,905
Vermont	352,608	842,013	955,617
Maine	83,800	219,500	250,000
New York	95,500	126,603	176,000
Virginia	51,000	113,079	127,819
Maryland	56,700	110,008	125,425
Total for the United States .	\$1,529,085	\$3,482,513	\$3,825,746

Limestone.—Deposits of carbonate of lime are sometimes precipitated from solution, but most frequently they are the accumulations of animal remains, generally of coralline animals. By these agencies vast stores of limestone have been built in all geological ages, and consequently every part of the country produces this stone. In Florida, and in many oceanic islands and coral reefs, accumulations of recent shells and coral fragments have been loosely cemented, forming a coquina which is used locally for building purposes. This coquina differs in no essential particular from true limestone, excepting in the degree of consolidation; and since it is being formed under our very eyes, it serves as an excellent illustration of the ease with which rocks may be consolidated when there is present an abundant supply of a very soluble mineral, such as calcite, which is the cementing material of limestone.

In colour limestone varies markedly, from black to pure white, with abundant blues, browns, and grays. The texture varies from a very fine grained compact rock to a semi-crystalline, and even a very coarsely crystalline marble composed of calcite crystals. It may be nearly pure carbonate of lime, or a nearly pure magnesian carbonate or dolomite; it may be a black carbonaceous or bituminous limestone; or it may pass by gradations from an argillaceous limestone to a limy shale; and between these various kinds there is every gradation.

Under the term *limestone* should properly be included only those rocks which are composed chiefly of carbonate of lime; but commercially, siliceous, argillaceous, and magnesian limestones are all included under limestone. Moreover, there is a peculiar complication resulting from the attempt to separate marble from limestone. When a limestone has been metamorphosed, the carbonate of lime becomes altered to crystalline calcite, and the impurities gather together either in bands of different colours or in bunches of various minerals. This results in the formation of true marble, which should very properly be separated commercially from ordinary limestone, since it is metamorphosed and crystalline, and, being capable of a high polish, serves for purposes for which ordinary limestone cannot be used. But under the term *marble*, in its commercial sense, is included many non-crystalline limestones, which, by polishing, show either banding or some desired colour, such as black. Consequently marble in its commercial significance is made to include stone which is not true marble. Nor is the term *limestone* any more exact, since, not only does it include many very impure limestones, but

also true marble, when this is not situated in positions favourable for quarrying, or has not a sufficiently fine texture, or cannot be obtained in sufficient quantities, or in large blocks.

Commercial limestone may be said to be any rock containing a sufficient quantity of carbonate of lime to pay for burning; and commercial marble may be defined as any limestone, crystalline or non-crystalline, which is susceptible of a polish, and has a colour and texture suitable for ornamental work, and a position favourable for economic extraction. The terms are therefore far from scientific. Properly speaking, marble is metamorphosed and either partly or completely altered limestone, usually semi or wholly crystalline. But since there is every gradation from one form to the other, it is difficult to always distinguish them, as, indeed, it is in the case of all sedimentary rocks, for there is every gradation from conglomerate to sandstone, from sandstone to shale, from shale to limestone, and from limestone to marble.

In 1889 the total supply of limestone produced in the country was used for the following purposes:—

USES OF LIMESTONE IN 1889.

Lime	\$8,217,015
Building	5,405,671
Street work	2,383,456
Flux	1,569,312
Bridge, dam, and railroad work	1,289,622
Miscellaneous	230,103
Total	<hr/> \$19,095,179

For some of these purposes it is not necessary that the rock should have particular qualities, but for others it should

be comparatively pure. This table does not fully represent the value of the industry, particularly that part of it which is represented in the manufacture of lime, and that used as a flux. Full returns have not been obtained from many blast furnaces which quarry their own flux, and there are, in operation upon farms, large numbers of lime-kilns for burning limestone to be used either as a fertilizer or a plaster. These two industries should have their total increased; and probably the total value of the limestone quarried and used for all purposes is over \$21,000,000.

PRODUCTION OF LIMESTONE IN THE UNITED STATES.

STATES.	1880.	1889.	1891.
Indiana	\$593,375	\$1,889,336	\$2,100,000
Pennsylvania	240,934	2,655,477	2,100,000
Illinois	1,320,742	2,190,607	2,030,000
Missouri	421,211	1,859,960	1,400,000
Ohio	669,723	1,514,934	1,250,000
Maine . . . . .	....	1,523,499	1,200,000
New York	207,000	1,108,830	1,000,000
Wisconsin	189,320	813,963	600,000
Minnesota	201,593	613,247	600,000
Total for the United States . .	\$6,856,681	\$19,095,179	\$15,792,000

The combined value of the marble and limestone industries in 1880 amounted to only \$6,856,681, while in 1889 it exceeded \$25,500,000, showing a striking increase in ten years. Thirteen states, California, Iowa, Alabama, Kansas, Kentucky, Nebraska, Texas, Vermont, Virginia, Maryland,

Connecticut, Massachusetts, and New Jersey, named in the order of their importance, each produced over \$100,000 and less than \$500,000 worth of limestone. Almost one-half of the limestone of Indiana and Illinois is used in building, nearly all of the output of Pennsylvania is used for lime and flux, and all of the output of Maine is manufactured into lime.

The following table shows the rank of the various states in the several industries:—

USES OF LIMESTONE BY STATES, 1889.¹

Uses	PENNSYLVANIA	ILLINOIS	INDIANA	MIS- SOURI	NEW YORK	OHIO	MAINE
Lime	II \$1,195,955	VIII \$366,245	IX \$340,315	VII \$46,390	III \$837,613	IV \$581,925	I \$1,523,499
Building	VIII 238,431	I 1,084,556	II 991,310	III 542,571	IV 441,291	V 407,388	
Street work	IX 72,512	II 505,576	III 316,722	I 670,351	IV 197,991	V 183,235	
Flux	I 919,083	II 166,507	VXIII 1,036	VXI 5,691	VII 32,750	III 105,963	
Bridges, dams, etc.,	IV 155,653		I 23,710	III 169,720	II 175,736	V 124,518	

Marble.—Vermont is the principal marble-producing state of the country, the most important quarries being situated near Rutland, where there are extensive beds of a well-crystallized white and blue banded, and a clouded blue marble associated with a pure white crystalline marble. In the West Rutland quarries the strata dip to the west from a gentle slope to a dip of nearly 80°; and, in these beds, quarries have been opened to a depth of over three

¹ The numerals refer to the relative rank of the various states in the different branches of the limestone industry.

hundred feet. This belt of limestone extends, with greater or less continuity, to Long Island Sound, but, in the greater part of it, the marble is not suitable for ornamental purposes; and, where quarried, is used chiefly as a source for lime.

The so-called marble of Tennessee is not in reality a marble, but is a partly metamorphosed limestone in which the abundant fossils still show plainly, and by their difference of colour and their form, give to much of it its particular value. There is a considerable variety of colour, from light pink to chocolate brown, and often mixtures of these colours. In New York a coarsely crystalline, mottled, and banded blue, greenish, and white marble is found in St. Lawrence County; and in Westchester County a mottled dolomitic marble is quarried. A dull brown limestone, containing fossils, is obtained in Greene County, and a black limestone occurs at Glens Falls, in Warren County, New York. Georgia, Maryland, California, Pennsylvania, and Virginia are also marble-producers, and in some other states this stone has been found. It may be safely predicted that the best marbles of the country have not yet been exploited; for, in the Cordilleras, there are extensive deposits of beautiful and variously coloured marbles, which will some day rival the best Italian products. As in the case of nearly all building-stones this region, because of its inaccessibility, has not been developed; but even at present it would be possible to put upon the market some of these beautiful stones.

In the Eleventh Census report both serpentine and onyx are included under marble, and we have no recent statistics of the production of these ornamental stones. Onyx is

found in this country only in the western part. There is a deposit of this stone in San Luis Obispo County, California, but, although it resembles the Mexican onyx, and is very beautiful, it has not as yet assumed marked importance, because of its inaccessibility. At present onyx is quarried in Arizona, about thirty miles east of Prescott. It outcrops here in a bluff, and is stratified with a breccia, being, apparently, a precipitation from lime-bearing waters which have received their carbonate of lime by percolation through the neighbouring igneous rocks. This onyx compares favourably with that of Mexico, but, although some is sold, our chief supply of this stone still comes from the latter country.

Serpentine is known to exist in various parts of the belt of metamorphic rocks, from New England to Georgia, and also in the Cordilleran metamorphics; but it rarely occurs in sufficient abundance and of the proper colour to be of economic value. There are, however, serpentine quarries in Maryland, from which a stone varying in colour from pale to dark green is produced. Serpentine is a product of metamorphism and alteration from certain rocks and minerals, notably from olivine and olivine-bearing rocks.

Over 80 per cent of the marble consumed in this country is produced at home, but considerable ornamental stone for interior decoration is imported, principally from Carrara in Italy, from which place we obtain three-fourths of our imports of this stone. Marble is used almost entirely for interior decoration, for ornamental work, monuments, grave-stones, and some of the more costly buildings. It is not nearly so commonly used for building purposes as the other stones.

PRODUCTION OF MARBLE IN THE UNITED STATES.

STATES.	1880.	1889.	1891.
Vermont	\$1,340,000	\$2,169,560	\$2,200,000
Tennessee	173,600	419,467	400,000
New York	224,500	351,197	390,000
Georgia . . . . .	....	196,250	275,000
California . . . . .	....	87,030	100,000
Maryland	65,000	139,816	100,000
Pennsylvania . . . . .	....	...	45,000
Total for the United States. .	\$2,033,595	\$3,488,170	\$3,610,000

Summary of Building-Stone Production.¹ — The ten leading stone-producing states in 1889 were Pennsylvania, Ohio, New York, Maine, Vermont, Massachusetts, Missouri, Illinois, California, and Connecticut, all of which produced more than \$2,000,000 worth of stone in the last census year. Five other states, Indiana, Colorado, Wisconsin, New Jersey, and Minnesota, produced over \$1,000,000 worth of stone in 1889. Forty-four states and territories produced \$53,035,620 worth of stone for building and other purposes.

Of this total, Pennsylvania supplied 13.8 per cent, or \$7,319,199 worth of stone. All commercial varieties are found there, but the chief products are limestone, slate, and sandstone. Ohio, which ranks as the second most important

¹ For a more complete statement of the economic importance of the stone industry in the various states of the United States, reference may be made to the Eleventh Census volume on *Mineral Industries*, pp. 595-606, and the *Mineral Resources of the United States*, Day (U. S. Geol. Survey) 1889-1890, pp. 373-440. An excellent book upon the general subject of building-stones is Merrill's *Stones for Building and Decoration*, New York, 1891.

stone-producing state, supplies almost exclusively sandstone and limestone, in the former of which it holds first rank.

All varieties of stone are obtained in the third state, New York, but the most important are limestone and bluestone. Maine owes its rank to the numerous granite quarries, and to the industry of lime production, for which purpose the entire output of limestone is employed. In Vermont the most important stone is marble, but slate is also quarried extensively, and in this industry Vermont holds second place, while in the production of marble it has an output nearly twice as great as all the other states combined. The granite industry, in which Massachusetts holds first rank, is the only important stone industry of the state, although small quantities of sandstone and limestone are also obtained. Missouri produces principally limestone and some granite, Illinois practically nothing but limestone, California supplies stone of several varieties for local and Pacific Coast consumers chiefly, and Connecticut is a producer of granite and sandstone. Indiana leads in the production of limestone, and this makes the greater part of its stone output; Colorado produces principally sandstone; Wisconsin chiefly limestone; New Jersey, sandstone, slate, granite, and limestone; and Minnesota, limestone and sandstone.

It will be noticed that the metamorphic rocks, slates, and marbles, and the granites, occur almost exclusively in the belt of metamorphic rocks extending from Canada to Georgia and in the area of metamorphics about Lake Superior. Other metamorphic areas, particularly in the Cordilleras, contain stores of these stones, but they will not be extensively quarried, except for local purposes, for the reason

that they cannot compete with the eastern stone found near the market.

The sedimentary rocks, limestones, bluestones, and sandstones, are obtained principally from the Central States, where the strata are all of Palæozoic age and nearly horizontal. Being horizontal, they are not too much altered or broken, and yet, on account of their great age, they are sufficiently cemented and indurated for building purposes. Not a small percentage of these stones comes from the strata of the same age, which are folded into the Appalachians; and by far the greater part of the Cordilleras are made up of similar sedimentary rocks, which, for the same reason, that applies to the metamorphic and igneous building-stones, are not of value except for local purposes.

There is no need of importing any kind of building-stone, and, if called upon, we could quarry enough of nearly all kinds of stone to supply the needs of the world. No other nation has an output of building-stone so varied and so great as that of the United States, and no other nation has such immense stores which are of good quality, but of no immediate value because of the absence of a market. As has been said above, a building-stone to be of value, this country must be either of exceptional quality or accessible to a good market.

The following table shows the output of all kinds of stone from the fifteen most important states, each of which produces over \$1,000,000 worth a year. In 1889 the production of these states was within \$10,000,000 of the total for the country.

PRODUCTION OF STONE IN THE UNITED STATES, 1889.

Pennsylvania	\$7,319,199
Ohio	4,561,590
New York	4,418,143
Maine.	3,968,838
Vermont	3,789,709
Massachusetts	3,307,578
Missouri	2,516,159
Illinois	2,208,503
California	2,126,515
Connecticut.	2,112,960
Indiana	1,933,319
Colorado	1,676,862
Wisconsin	1,264,016
New Jersey	1,172,119
Minnesota	1,102,008

Total for the United States . . . \$53,035,620

BUILDING-STONE PRODUCTION OF THE UNITED STATES.

KINDS.	1880.	1889.	1891.
Limestone	\$6,856,681	\$19,095,179	\$15,762,000
Granite	5,188,998	14,464,095	13,867,000
Sandstone	4,780,391	10,816,057	8,700,000
Slate	1,529,985	3,482,513	3,825,746
Marble	2,033,595	3,488,170	3,610,000
Bluestone . . . . .	. . .	1,689,606	....
Total building stones and lime	\$18,356,055	\$53,035,620	\$47,294,746

*Natural and Artificial Cements.*¹

By mixing burned limestone or lime with sand and water, a plaster is produced, which, upon drying, hardens to form a cement, the ordinary material used for plaster; and the importance of this industry may be inferred from the fact that, in 1892, 70,000,000 barrels (200 lbs. each), valued at \$38,500,000, were produced in this country. Cements which have the power of setting and hardening under water are commonly called hydraulic and Portland cements. These are either a natural or artificial mixture of carbonate of lime and clay heated to a high temperature and then ground to a powder.

Argillaceous limestones sometimes contain the proper proportion of clay and carbonate of lime for the formation of hydraulic cement; but more commonly the per cent of these materials is not exactly correct, and then either a poor cement or a valueless product results. Properly speaking, hydraulic cement is made from natural hydraulic limestones, burned at a moderate temperature, while Portland cement is made from a mixture of chalk, or marl, and clay burned at a high heat. In this country hydraulic cement is made chiefly in New York state, from a shaly limestone, which occurs at the top of the Salina group, and extends through several counties. The industry is principally concentrated in Ulster County.

Portland cement, which sets more slowly, but produces a much harder and stronger cement, is manufactured in England, Germany, and France on a very large scale; but

¹ This industry depends so largely upon the method of manufacture, that little is necessary here, excepting to point out the source of the materials used. Valuable accounts of the cement industry will be found in *The Mineral Resources of the United States*, Day (U. S. Geol. Survey), 1897, pp. 529-538, and in Rothwell's *Mineral Industry*, 1891, pp. 49-56.

in this country very little is produced, although calcareous marls and chalks suitable for its manufacture are found in numerous places, and the industry promises to grow rapidly. Great care is needed in obtaining the proper proportion of clay and carbonate of lime, and also in mixing these together.

The following analyses will give an idea of the chemical character of the cement-rocks and cement:—

ANALYSIS OF HYDRAULIC CEMENT ROCK, ROSENDALE,
ULSTER COUNTY, NEW YORK

Carbonate of lime	45.91
Carbonate of magnesia .	26.14
Silica and insoluble	15.37
Sesquioxide of iron, and alumina	11.38
Water and undetermined compounds	1.20

There is, however, great variability in composition, but the above is a fair average analysis.

ANALYSES OF PORTLAND CEMENT MIXTURES

	COLLIER (PA.) NATURAL ROCK AND LIMESTONE		WAINWRIGHT (N. Y.) CLAY AND MARL		YANKTON (SOUTH DAKOTA) CLAY AND LIMESTONE	
	Argillaceous Limestone	Limestone	Clay	Marl	Clay	Limestone
Lime	37.60	50.15	11.25	51.5	5.28	51.00
Silica	18.34	4.46	44.74	1.06	61.53	4.14
Alumina	4.08	1.00	18.70	.64	20.74	1.81
Sesquioxide of iron	8.41	.48	4.25	.5	4.01	2.72
Magnesia	1.39	.87	1.29	.91	1.72	Trace
Alkalies	.19	Trace	1.20		2.29	Trace
Carbonic acid	31.05	40.40	7.50	40.70	3.09	39.99
Sulphuric acid			2.78	2.07		
Sulphur	.73	.15			1.26	.50
Water			9.25			
Organic and undetermined,	3.21	2.49		2.86	.08	
Total	100.00	100.00	100.96	100.14	100.00	100.16

There is, therefore, a marked variability in the kind and composition of the rock used in the manufacture of these artificial cements. A greater uniformity is obtained in the products, but even here there is some variety.

ANALYSES OF NATURAL AND PORTLAND CEMENTS.

	HYDRAULIC.		PORTLAND.	
	Rosendale, Ulster Co., N. Y.	Akron, N. Y.	Coplay, Pa.	Onondaga Co., N. Y.
Silica	22.75	20.64	20.64	22.10
Alumina	16.70	6.42	6.93	6.84
Sesquioxide of iron			5.41	2.10
Lime	37.60	54.77	62.79	63.00
Magnesia	16.65	9.17	1.72	.97
Alkalies . . . . .	...	....	.27	4.00
Carbonic acid	5.00	....	.99	.90
Undetermined	1.30	....	1.14	.09

PRODUCTION OF CEMENT IN THE UNITED STATES.

	HYDRAULIC.		PORTLAND.		TOTAL VALUE.
	Barrels.	Value.	Barrels.	Value.	
1882	3,165,000	\$3,481,500	85,000	\$191,250	\$3,672,750
1885	4,000,000	3,200,000	150,000	292,500	3,492,500
1892	8,132,593	5,549,163	525,360	1,036,935	6,586,098

In 1891 the total value of the hydraulic cement output was \$5,613,522, of which New York produced \$1,046,279, Indiana-

Kentucky \$983,456, and Pennsylvania \$536,600. Of the total of \$1,067,429 worth of Portland cement produced in this country in 1891, Pennsylvania supplied \$532,850, and New York \$290,250. Our imports of cement in 1892 amounted to \$3,378,824, this being principally Portland cement.

CHAPTER XVII.

SOILS, CLAYS, FERTILIZERS, ARTESIAN WELLS, AND MINERAL WATERS.

*Soils.*¹

THE subject of soils cannot be treated here in more than a very general and cursory manner, and the chemical consideration must be entirely omitted. In general, soils may be classified into two groups, — indigenous and transported. The first group includes those which have been formed approximately at the point where they rest, the second those which have been borne from some outside source. Of these there are several kinds.

Residual soils may be classed as indigenous, and they result from the decay and disintegration of the rock which underlies them. A rock, even the hardest and most durable, is susceptible to changes in structure or even in chemical composition under the ordinary influences of weather. The building of sandstone, limestone, or granite shows the effect of weathering by a crumbling which results from long-continued exposure. The rain dissolves soluble portions and forms crevices into which water may enter, and this, if frozen, prys open the crevices and aids in the disintegration. Sudden changes of temperature from warm to

¹ Professor N. S. Shaler has prepared an admirable treatise upon soils, which is published in the Twelfth Annual Report of the U. S. Geol. Survey, pp. 213-345.

cold, or from cold to warm, cause contraction or expansion, which aids the fragments in breaking. Lichens clinging to the wall send root-like threads into the crevices, and these, upon the growth of the plant, tend to wedge fragments from the rocks.

It is exactly this process which causes the formation of residual soils. The rock disintegrates, percolating water permeate the resulting material, and, dissolving the soluble minerals, carries them away in solution. The work which lichens at first did on a small scale, is continued on a larger scale by the prying action of the roots of larger plants and trees. The ants, the rodents, the earthworms, and the many creatures which live in the soil aid in the work. As a result of these various agents, rock crumbles and tends to become ever finer in texture, while at the same time the soluble salts are removed. There is a tendency, therefore, to concentrate the insoluble particles and thus form a residue, — the normal residual soil.

By the decay of rocks, the soil at first maintains certain characteristics of the parent rock, and a limestone soil therefore differs from a granite soil. In other words, certain of the soluble salts are not removed, and these give to the resulting product a character indicative of its origin. Ultimately, however, all of the soluble salts would be removed, and the resulting soil would not vary essentially from one rock to another. It would be composed of the nearly insoluble silica, kaolin, and other similar products, whether the source were limestone or granite.

In the rocks — in granite, for instance — there are minerals which by their decay form salts of potassium, sodium, calcium, etc., which are valuable as plant food, and it is these

which the plants absorb from the soil. On the other hand, there are contained in many rocks organic remains, either animal or plant, — as, for instance, the organic contributions forming limestone, — and these are especially rich in plant food. Indeed, during the formation of a soil, organisms, particularly plants, at their death, enrich the soil which has supported them, by returning to it a portion of that which they have extracted from the air and the soil. The decaying vegetation forms a loam, particularly in swampy places, where it is protected from decay and entire dissipation, and the influence of this is felt to a distance of several feet below the surface.

At times the conditions favour the formation of an organic soil. This is particularly noticeable in swampy regions, where vegetable growth is rapid and decay slow. Deep loams and peat bogs result, and these, when properly drained, make valuable soils.

In the ocean, material is deposited sometimes in the form of organic remains, sometimes as inorganic sediments. When these are raised above the sea, they may be in one of two conditions, — either consolidated or loose and unconsolidated. If the former, they must be disintegrated before forming soils; but if in the latter condition, they are suited to the growth of plant life as soon as drained. It becomes a question whether the latter are to be considered indigenous or transported soils; but, since there is every gradation from these to the typical transported soil, and, on the other hand, between the unconsolidated and consolidated rocks, they may be considered to be intermediate in position. Material is prepared upon the land by disintegration, and transported seawards, where it is assorted and deposited;

and upon the elevation of that part of the sea-bottom it may again begin the cycle.

Instances of such soils are found in the coastal plains extending from New Jersey to the Rio Grande, but most of these are still too swampy to be of use to man. Of the organic indigenous soils, the swamp lands of Florida, the Dismal Swamp, and the innumerable morasses and bogs of the northeastern states are illustrations. A residual soil covers the greater part of the area of the United States south of the glacial belt, and throughout this area the character of the soil is distinctly influenced by the underlying rocks. This soil varies in thickness up to many feet, and in some tropical regions, such as Brazil, this residual soil has a thickness of several scores of feet.

Excepting on a plain, it is not strictly accurate to speak of an indigenous soil. Upon hillsides the action of gravity tends to cause the soil to creep slowly down toward the valley, and even upon moderate slopes this creeping action is noticeable. In arid lands the peculiarities of the climate make this more noticeable. Heavy rainfalls occur at rare intervals, and the tendency is to cause a wash of the disintegrated materials from the base of the mountains out upon the plateau. Gravel slopes are thus formed, as the result of the action of gravity, aided by the wash of the heavy rains.

From these types of partly moved soils, there is every gradation to the talus soil which forms at the base of a cliff by the constant dropping and subsequent disintegration of rock fragments. Eventually the talus is built up to a point where its slope meets the top of the cliff, or a point where the talus slope is continued in the hill. In other words, the hill wears back by weathering; and this weathered slope and the talus

slope become continuous. If, however, a stream flows at the base of the cliff, and removes the talus, the above condition may for a long time be delayed. The talus soil resembles the indigenous soil in the fact that it has a character resembling that of the rock of the cliff, and that it is derived by disintegration. But, on the other hand, it has been removed for some distance, and is very liable to be a commingled product derived from the several kinds of rocks which form the cliff. These soils are very common in the Cordilleras at isolated points.

In their passage to the sea, streams take such fragments as they find within their grasp, and transport them down stream, always tending to divide them into smaller fragments. In the course of their development, streams build flood plains, and often terraces and deltas, by reason of certain causes which cannot be explained here. These, which are usually excellent soils, are generally fine-grained in texture, and are composed of materials from all parts of the drainage area above the point of deposit. The Mississippi valley furnishes the best illustration of this class of soils, but in a minor way all the smaller rivers are likewise flood-plained. Akin to these soils are the sea-bottom sediments which are raised above the sea, and the lake-bottom deposits which result from the filling and drainage of lacustrine bodies.

Another group of transported soils, although of very little importance, is that of aërial or æolian soils. Even in moist climates, there are times when the dust blows about, and this aids, not only in transportation, but also in the disintegration of rock fragments. In the arid lands this blowing about of sand and dust becomes of much more importance, and all the soils there are in a measure transported by this means.

Locally, in these regions, where the conditions are favourable, and also along lake and sea shores, blown sands form extensive tracts of sand-dunes which are typical æolian soils, usually barren of vegetation, not alone because of the fact of their constant movement, but also because they are actually barren of plant food. Usually quartz and sand grains predominate, and these form a porous deposit, through which the water passes freely without causing a decay of the minerals and the formation of plant food. Only hardy and sand-loving plants are able to obtain a footing there; but if these succeed in growing in sufficient abundance to prevent the movement of the sand, they soon bring about the disintegration of the grains and the formation of a soil capable of sustaining other forms of vegetation.

A final important group is that of glacially formed soils. In certain mountains snow accumulates, and, moving down the valleys, forms a glacier which ploughs against the valley bottom and sides, rasping and grinding off fragments as it moves, and transporting these to its terminus, together with the fragments which fall upon it from the overhanging cliffs. Thus, at any given time, there is beneath a glacier a deposit consisting of large boulders and finer fragments, even fine-grained clay, all mixed intimately. If the glacier should disappear, the valley bottom would be covered with this material, forming a glacially transported soil. At the terminus of the glacier, moraines are formed of the material brought by the ice, and left when it was able to move no farther. From beneath the ice, streams issue; and these assort the materials, leaving the large boulders behind, carrying the fine clay some distance from the glacier, and depositing sand plains and terraces between these two points.

Almost exactly this same condition has been experienced by the northern sections of this country, north of a line extending approximately from Nantucket, through Long Island, central New Jersey, northwestern Pennsylvania, Cincinnati, Ohio, Wisconsin, and thence northwestward to Dakota. Nearly all of this region was beneath an ice-sheet resembling that of Greenland. Any soil which may have existed before the oncoming of the glacial period was swept away; and when finally the ice melted, the surface was littered with a glacially transported soil, in some places morainal, in some the general sheet of unstratified till or ground moraine, and elsewhere with sand plains and terraces.

In a limestone region the soil contains not only fragments of this material, but of many rocks derived from more northern regions. Where the motion of the ice was for a long distance over a limestone belt, as in some of the north and south valleys of New England and New Jersey, the influence of the limestone is markedly noticeable in the soil. But it is not uncommon to find, over a given stratum, a soil almost free from this material.

In places the deposit is thick, again it is thin, and, over large areas, no glacial soil was left. The time since the close of the glacial epoch is so short that in such places residual soils have not been formed, and the bare rock outcrops. Where the country rock is hard, well jointed, and not easily disintegrated, as in the granite and gneiss regions of New England, the proportion of boulders in the soil is very great, and agriculture is carried on with difficulty. Thus there is a marked difference in the character of the soil north and south of the terminal moraine.

In soils of all these characters plants of various kinds

grow. Some are well adapted to nearly all varieties of plants, others support only certain kinds. In a state of nature the plants rob the soil of certain elements, but they return to it not only a part of that which they extracted, but also some of the carbon which they have absorbed from the air. Moreover, they furnish a vegetable coating, which protects the soil from being washed away, and furnishes water percolating through it with certain acids which disintegrate the particles of rock. It also delays the passage of this percolating water so that it does not sink readily into the soil and wash away the plant food.

Man has come into the field with his modern methods and implements, and has begun to rob the soil of its natural stores of plant food. Extravagant and even foolish methods have been introduced, and, in this country in particular, thoroughly prodigal methods have been adopted. The abundance of land, its virgin richness, and the fact that we have not had centuries of experience in tillage, have tended to make us thoughtless of our duty to the soil and our descendants. The wealth of the nation is largely dependent upon the tillage of the soil, and methods which will ultimately prove disastrous should be avoided. Already in the older settled districts the soil is impoverished, and the time is not far distant when our western farm lands will need to be treated scientifically or be abandoned. At present the average farmer is taking from the soil all it will yield and returning nothing to it. Moreover, he is interfering with the natural formation of plant food by the removal of the loam, and by rendering the soil porous by ploughing so that water passes through it as it does through a sand-dune. He should return that part of the

vegetation which he does not use, and indeed he must do more. The peat beds, swamp loam, manure, marls, guanos, and phosphates must be more commonly used.

*Clays.*¹

An almost infinite variety of clay occurs in this country, and its abundance is so great that for ordinary purposes it is readily accessible. There are numerous ways in which it is derived, the most common being as a result of rock decay. Beds of clay are found throughout the sedimentary strata, either still incoherent, or consolidated, and sometimes even transformed to slate. These are chiefly formed as sediments, by the deposition of the fine-grained products of rock decay. Ordinarily these are too impure for any but the roughest uses, and some of them cannot be used at all. For some purposes, such as the manufacture of white pottery, pure kaolin is needed, but for tiling and bricks, impure clays may be used.

The first stage in the formation of much of the clay is the decomposition of the rock, a process which is everywhere in progress. The mineral which is of most importance in the production of the finer grades of clay is feldspar, which, by its decay, loses the sodium, potassium, and other soluble salts, while, as an ultimate product, kaolin, or hydrous silicate of alumina, remains. Such clays in place are very rare, for they are usually mixed with impurities of one kind and another; but in many cases, for the better class of porcelain and other ware, rocks which are

¹ The subject of clays is admirably treated by Professor R. T. Hill in the *Mineral Resources of the United States* for 1891, pp. 474-528.

disintegrating, and, in some cases, pure feldspar, are crushed and washed to remove the impurities.

More commonly workable clays occur in beds where they have been deposited by sea or lake, in some cases in the form of nearly pure kaolin, but more commonly as impure clays, varying greatly in composition, texture, and colour. From these, bricks, drain tiles, chinaware, furnace linings, pottery, various utensils and ornamental pottery, etc., are manufactured by the aid of heat and partial melting. Not a little clay is used for purposes of adulteration and as a filling for cheap grades of paper.

For these several purposes different kinds are needed, and consequently different industries spring up in various localities. Clays known as fire-clays are suited to withstand high temperatures by reason of the absence of alkaline material. These are particularly abundant in the Carboniferous rocks associated with coal beds, the plants having been instrumental in the withdrawal of the alkalies. Brick clays must be made of a natural or artificial mixture of sand and clay. When a red colour is needed, iron salts must also be present. Certain alkalies are also needful to aid in the partial fusion of the clay when heated.

Some brick clays are the result of residual decay; some are worked-over products of disintegration deposited in water, and in this country a large proportion of these clays are directly or indirectly the result of glacial action. As the ice moved over the rocks, they were ground and rasped until a rock flour was produced which was sometimes deposited in marginal lakes, or in the river-terrace plains near the ice front, and sometimes deposited directly from the

ice when it melted. The distribution of these clays in the glacial belt is very widespread, and every state and nearly every district has such clays for the manufacture of brick for local demands. Certain large centres which produce brick of an exceptional quality ship some of their output to a considerable distance; but most of the producers supply only local markets. This is less true of the other clay industries, excepting those producing the coarsest products; and very fine ornamental ware is sent from one country to another.

Clays are of all ages from the Cambrian to the present, but in this country the most important are of Cretaceous, Tertiary, and Quaternary age. The brick clays are chiefly of Quaternary age, being either recently deposited in river valleys, or of glacial origin. Fire-clay occurs abundantly in the Carboniferous, and some in this country occur elsewhere in the Palæozoic. In addition to actual clays, flint, quartz, and feldspar are ground up and used as clay. There are large quantities of these minerals, as well as of clay, which are not at present utilized.

Notwithstanding the great importance of the industry of brick production, there are no statistics available. In '91 the value of the potter's materials, including kaolin, fire-clay, ground flint, and feldspar, was over \$1,000,000. New Jersey is the most important state in this respect, but many others have valuable pottery industries. Probably the brick industry is many times more valuable than that of the manufacture of pottery.

The industry of feldspar production for grinding and mixing with clay and for a glaze is centred in Maine, Connecticut, New York, and Pennsylvania. The annual

product varies from 8000 to 15,000 long tons, valued at about \$5 a ton, and this comes from coarse granitic or pegmatite veins. Flint occurs in bands and nodules of concretionary origin in limestones and chalk. It is an impure form of silica, and is used extensively in the manufacture of pottery. There are vast quantities in the west and southwest which are not at present utilized. In 1891, 15,000 long tons, valued at \$60,000, were produced in the United States.

Fertilizers.

General Statement.—Various substances are used for the purpose of returning to the soil the elements needed in plant growth, thereby enriching impoverished soils. Manure and other waste products of organic origin are commonly used for this purpose, and there are extensive establishments for the manufacture of artificial guano from the remnants of fish and other animals, obtained during the process of preparation for the market. Vegetable products are also made to give up their plant food to the soil. Sometimes the plants which have grown upon the field are allowed to decay there, and at times loam and peat are added to the soil. These products do not come within the scope of this work, and none of them, with the exception of artificial guano, are of more than local importance. There are, however, several classes of important economic products which are of use for returning to the soil needful substances which have been extracted by plants. These are limestone, marl, gypsum, and the various phosphates.

Limestone and Marl.—It is a well-recognized fact that limestone soils are rich in plant food, and consequently the

addition of this rock to a poor soil is of value. This is due partly to the presence of the carbonate of lime, and partly to other substances of organic origin furnished the limestone by the animals which formed it. For the purpose of a fertilizer, limestone is burned to form lime, and then spread upon the soil. A portion of the lime product mentioned in the preceding chapter is used for this purpose, while many farmers burn limestone for their own or for local use in regions where it can be easily obtained. There are no statistics for the production of lime for fertilizing purposes.

Marl is a calcareous clay, owing its calcareous nature to the presence of numerous shells of mollusca. Being a soft clay, it is easily obtained; and before the introduction of cheap phosphatic fertilizers, it was extensively used for fertilizing purposes, particularly in New Jersey, where it is found most abundantly. This substance occurs locally in many places, in the bottom of swamps, and it should be of more local importance than it is. In the coastal plains of Cretaceous and Tertiary age there are extensive deposits of marl and greensand; and since these are at present used only for local purposes, statistics of their production are difficult to obtain. During the census year 1880 the value of the marl product was approximately \$500,000, and in 1891 only \$67,500, this representing 135,000 tons of marl. This calcareous clay is also of value in the manufacture of Portland cement.

Gypsum. — This mineral, the sulphate of lime, is used for two purposes principally,—one as “land plaster” for a fertilizer, the other, and the most important, calcined, to form plaster of Paris. Gypsum occurs in all rocks, in minute quantities; but in many sedimentary strata, it is suffi-

ciently abundant to give to water percolating through them a certain peculiarity known as "hardness." The water of nearly all rivers and lakes, and of all oceans, carries it in solution; and when lakes fail to overflow, and are transformed to dead seas, this mineral becomes concentrated, and may finally be precipitated in beds. Much of the supply obtained in this country is associated with salt, and has probably originated in this way. In the Cordilleras there are large areas of gypsum, called white sands, in the dried-up beds of extinct lakes; but this is at present of no value except for local purposes.

There is still another way in which this mineral may be formed in the rocks, and some believe that many of the gypsum beds are of this origin. This is by the alteration of beds of limestone, through which sulphurous waters are percolating. It is doubtful how far this can be extended to account for the commercial deposits of gypsum, but some of this mineral is undoubtedly formed in that way. Sulphurous waters are not uncommon, the sulphur being furnished by decaying organic remains or by iron pyrites; and these, coming in contact with limestone beds, may very readily alter them to the sulphate of lime.

The association of gypsum with salt, however, indicates that much of it is the result of precipitation from salt lakes; and for the western deposits this is unquestionably the true explanation. In different parts of the world, different ages have had prevailing conditions of aridity, attended by the formation of dead seas; but in this country the Permian, Tertiary, and Quaternary have been the most important periods in which arid conditions have prevailed. This applies to the western part of the country; and

there is some reason to believe that, during the Palæozoic, there were periods of aridity in the east.

PRODUCTION OF GYPSUM IN THE UNITED STATES, 1891.

STATES.	CALCINED FOR PLASTER.	FERTIL- IZER.	SOLD CRUDE.	TOTAL PRODUCT. SHORT TONS (2000 LBS.).	TOTAL VALUE.
Michigan	\$173,175	\$28,550	\$22,000	79,700	\$223,725
Kansas	159,832	210	1,280	40,217	161,322
New York . . . . .	....	53,513	5,058	30,135	58,571
Iowa	53,250	4,845	....	31,385	58,095
Virginia . . . . .	....	22,222	352	5,959	22,574
South Dakota . . .	4,938	4,680	....	3,615	9,618
California, Ohio, Utah, } and Wyoming . . }	90,810	3,336	....	17,115	94,146
Total	\$482,005	\$117,356	\$28,690	208,126	\$628,051

GYPSUM PRODUCTION OF THE UNITED STATES.

1880	\$400,000
1885	405,000
1890	428,625
1892	675,000

In 1891 we imported \$226,319 worth of gypsum.

Phosphatic Fertilizers.¹—*Mineral Phosphate.* The phosphatic fertilizers may be divided into mineral phosphates, of which apatite is the only representative, and rock phosphates which consist of guano, bone beds, and phosphatic nodules. Mineral phosphate, or apatite, the phosphate of lime, occurs in nearly

¹ A valuable treatise on *The Nature and Origin of Phosphate of Lime*, by R. A. F. Penrose, Jr., forms Bull. 40, U. S. Geol. Survey.

all eruptive and metamorphic rocks, generally in small grains and crystals, and in such small quantities that it does not sensibly increase the value of the enclosing rock as a soil-producer. In some rocks, principally in the metamorphic limestones associated with the Archean, apatite is often more abundant, and seems here to be the result of segregation into crystal form of the phosphatic substances originally disseminated through the limestone in the form of organic remains. The bones of vertebrates, the flesh of many animals, and, in some cases, the tests or shells of animals, particularly certain Crustacea, contain some phosphate of lime; and as a result of this, certain limestones are sufficiently phosphatic to make high-grade soils. But there is no reason for believing that the apatite which occurs in igneous and metamorphic rocks is of organic origin; but, on the contrary, this is probably the *original* source of the organic phosphatic materials extracted by the intervention of organisms.

Apatite is not mined in this country; but in Canada large quantities of it occur in veins in the Laurentian limestones and gneisses, near Ottawa, Perth, and Kingston. Here it is mined, separated by hand, and crushed, chiefly by the farmers who own the land and by small companies. A great decline in this industry has been caused by the competition of the South Carolina and Florida phosphates.

Guano.— This is the excrement of birds, such as divers and penguins, which resort in great numbers to some of the islands off the west coast of South America. It is found elsewhere, but the climatic conditions have not favoured its accumulation into extensive deposits. In 1804 Humboldt first called attention to the deposits of guano on the Chincha Islands, off the coast of Peru; and from 1842 to 1873, when

they were exhausted, nearly 14,000,000 tons, valued at from \$45 to \$70 a ton, were exported from there. Since then other islands have been producing guano; and although the older deposits are approaching exhaustion, the province of Tarapaca and the off-lying islands are still exporting this substance. In 1879 Chili seized these deposits, and still controls them. Chili exported, in 1890, 41,323 metric tons of guano, valued at \$1,237,003; but the time is not far distant when these islands will cease to produce guano. Smaller quantities are obtained in the Argentine Republic and Uruguay.

Rock Phosphates.—In this country the most important fertilizer is the rock phosphate, which exists in the form of bone beds and phosphatic nodules of concretionary origin, usually occurring together; and the recent discoveries of these substances have given to this country the leading rank in the production of natural fertilizers. South Carolina and Florida are the important phosphate-producing states, but deposits also exist in North Carolina, Alabama, and other southern coastal states. These deposits consist of a white phosphatic limestone or a limy marl-like clay containing layers and nodules of more pure phosphate of lime and bones and teeth of mastodons, sharks, and other land and marine animals.

The South Carolina deposits were recognized in 1797; but it was not until 1867 that their true value was known, and since then the production of phosphates in this state has rapidly increased. There are two methods of mining these deposits: one dredging in the river beds, the other removing the "land rock" by means of open trenches. The phosphate is then crushed, washed, dried in kilns, and finally converted into superphosphates. Beaufort is the principal locality, and here, as well as elsewhere, there is a

wide variation in the character, composition, and distribution of the phosphates; but they are all distinctly bedded with the other strata of Tertiary age.

The following table shows the increase in output of phosphate rock in South Carolina, a marked decrease being noticed since 1889, when the Florida phosphates became of importance. In 1890, 212,102 tons were obtained from the rivers by dredging, and the balance of the 537,149 tons from the land rock.

PRODUCTION OF PHOSPHATE ROCK IN SOUTH CAROLINA.

	LONG TONS (2240 LBS.).
1867	6
1868	12,262
1870	65,241
1875	122,790
1880	190,763
1885	395,403
1889	548,585
1890	537,149
1891	475,506
1892	350,000

Deposits of phosphate of lime were discovered in Florida in 1883, but not until 1888 were they known to exist in large quantities. In this year a fossil tooth was found in a white subsoil, and the latter upon analysis was found to be an important phosphate rock. Great excitement and active exploration followed, and extensive developments have been made which prove that this area is the largest and most important phosphate region in the country. The phosphate is in the form of (1) layers and nodules, called respectively "hard rock" and "land pebble"; (2) less pure phosphatic limestone, filling the spaces between the nodules and layers, called "soft rock"; (3) vertebrate fossils; and (4) "river

pebbles," which are derived from the land deposits washed down and accumulated by the streams. The following table shows the remarkably rapid development of the phosphate production of Florida:—

PHOSPHATE PRODUCTION OF FLORIDA.

YEAR.	PRODUCT.	
	LONG TONS (2240 LBS.).	VALUE.
1888	3,000	\$25,000
1889	4,100	32,800
1890	46,501	338,190
1891	112,482	703,013
1892	262,382	....

The following table of analyses shows the composition of these phosphates:—

ANALYSES OF SOUTH CAROLINA AND FLORIDA
PHOSPHATE ROCK.

	LURAVILLE, FLORIDA.	SOUTH CAROLINA.
Phosphoric acid (P_2O_5)	33.91	26.0 to 29.0
Lime (CaO)	47.02	35.0 to 42.0
Alumina (Al_2O_3)	2.37	Traces to 2.0
Ferric oxide (Fe_2O_3)	1.46	1.0 to 0
Magnesia (MgO)	0.39	Traces to 2.0
Alkalies (Na_2O)	0.19	. . .
Sulphuric acid (SO_3)	0.36	0.5 to 2.0
Fluorine (Fl)	2.35	1.0 to 2.0
Chlorine (Cl)	0.08	....
Silica (SiO_2)	0.10	4.0 to 12.0
Carbonic acid (CO_2)	2.67	2.5 to 5.0
Insoluble matter	5.07	2.0 to 6.0 ¹
Moisture	3.96	0.5 to 4.0

¹ Organic matter and combined water.

The price of phosphate rock varies greatly according to the proportion of phosphate of lime, but in 1891 it averaged about \$6.25 a ton. No doubt these deposits will in time be exhausted, but there are still immense stores in sight and enough to last for long periods of time. France, Belgium, and some other countries, contain phosphate beds of similar character and origin.

The origin of these deposits is from organic remains, as is indicated by the presence of bones of vertebrates. For some reason both land and marine vertebrates resorted to the estuaries and bays, and their remains became commingled. In Florida, at the time of formation of the phosphate beds, there existed above the sea a series of small keys and islets bathed by the warm southern currents; and in the straits between them marine life abounded, while upon the land, birds and mammals thrived. In the shallow coastal waters and on the shores, the bones of these animals were accumulated.

One may obtain a possible clue to the mode of accumulation of these remains by a study of the Big Bone Salt Lick of Kentucky to which mammals resorted for salt in large numbers, and, becoming mired or killed by carnivorous animals, their bones have accumulated for ages. Great quantities of bones of all kinds are gathered together in this great mammalian cemetery. Similar conditions may have existed in Florida and South Carolina, and this, added to the excrements of birds, may suffice to account for these deposits.

The recent (1893) disastrous hurricanes on the Gulf Coast furnish a suggestion concerning the possible accumulation of these land and marine vertebrates. Extensive floods have been produced on the low-lying islets of this coast by the high water accompanying these storms, and many hundred

lives have been lost in consequence. The similar typhoons of Asia have caused the destruction of hundreds of thousands of human lives. These waves, by stranding the larger marine vertebrates and at the same time drowning many of the land mammals, might readily have caused these phosphate beds. Being in the track of many of the West India hurricanes, these keys were favourably situated for these peculiar conditions; and, while the storms were frequent enough to cause much destruction, they were not frequent enough to completely devastate the region. At least, this is the case at present, since man himself inhabits the similar islets on the Gulf Coast.

Secondary changes consisted in grinding the phosphatic material to clay under the action of the waves, and later the concretionary gathering together of the phosphate of lime into layers and nodules. The "river pebbles" represent a still later process of concentration by the action of river erosion.

The following tables show approximately the production of phosphate of lime in the world and in the United States for a series of years:---

PRODUCTION OF PHOSPHATE OF LIME IN THE WORLD, 1890.

METRIC TONS (2204 LBS.).

United States	518,835
Belgium	280,000 ¹
Venezuela	60,000
Chili ²	41,323 ³
Canada	23,588
Great Britain	18,295
Peru ²	17,000 ¹
Uruguay ²	9,945 ³
French Guiana	3,500

¹ Estimated.

² Guano.

³ Exported.

PRODUCTION OF PHOSPHATE ROCK IN THE UNITED STATES.

METRIC TONS (2204 Lbs.).

1880	214,229
1882	337,500
1884	438,830
1886	437,579
1888	455,892
1890	518,835
1891	597,589
1892	651,801

The value of the output for 1892 was \$2,361,219.

*Artesian Wells.*¹

It is usually possible in moist countries to obtain a water supply, sufficient for ordinary purposes, by means of wells of very shallow depths; and it is not uncommon in such regions to find actual springs outcropping at the surface. These rise through joint planes, or along faults in some cases, but much more commonly they represent the escape of underground water at some favourably situated point on a hillside or at the base of a hill. The most common condition is where a porous stratum is underlain by an impervious layer, such as clay. Water, passing through the porous layer, encounters the impervious stratum and flows over it in the direction of its dip, and if this stratum outcrops on a hillside, a spring is formed. The contact of a deep soil with impervious rock, or of any pervious and impervious layer,

¹ A very valuable and comprehensive treatise on artesian wells, prepared by Professor R. T. Hill, is published by the Department of Agriculture under the title of *The Occurrence of Artesian and Other Underground Waters in Texas*, etc. A paper on artesian wells by Professor T. C. Chamberlain is also found in the Fifth Ann. Rept., U. S. Geol. Survey, pp. 125-173.

produces the same condition. So common is the association between clay strata and springs that such a stratum is usually indicated at the surface by a line of springs where it outcrops.

Springs are usually superficial phenomena, and a series of droughts, or even a single drought, will frequently cause them to disappear, showing how shallow is their origin. There are, however, some which are deep seated in origin, and these usually rise in permanent and extensive flow through fissures in the strata. Still another kind of large spring is the type which forms in limestone regions where much of the drainage is underground. In river valleys, and sometimes on plains, these underground streams reach the surface as extensive springs.

Artesian wells are deep-seated springs artificially formed, or, more exactly, deep-seated bodies of water tapped by artificial borings and rising to the surface under natural hydrostatic pressure. A spring which rises along a fault plane closely resembles an artesian well, with the exception that its escape to the surface is provided for by a naturally formed channel,—the fault plane instead of an artificial well.

The depth of artesian wells varies from a few score to several thousand feet, and all depend upon a few simple principles. Percolating water divides itself into two parts, one portion escaping, after a very short journey, in the form of springs or by general seepage, the other portion commencing a long underground journey. The latter portion naturally seeks the easiest paths, and these are in the porous rocks. Moreover, under the influence of gravity there is a tendency for the water to go deeper into the earth; but, on

the other hand, as the depth increases, there is an increasing hydrostatic and rock pressure which tends to force the water to the surface. This is not sufficient to force it upwards through the rocks against gravity unless a channel is furnished. If the strata are fissured, the water passes to these fissures and escapes to the surface naturally; but if they are not, it becomes entombed.

In the case of horizontal rocks water percolates through them, but its progress is retarded by the presence of impervious layers. The most favourable condition for the accumulation of water in the strata is in inclined layers, since here all of the strata outcrop at some point on the surface, and slope downward into the earth with a greater or less angle of dip. Where a porous stratum, such as sandstone, outcrops, the water that falls upon the area of outcrop readily soaks into the ground, and much of it is able to begin an underground journey. Naturally, if the dip is slight, there is a greater area of outcrop than in the case of a steeply inclined bed. Where the sandstone is overlain and underlain by an impervious stratum, such as clay or a clay rock, the water is prevented from escaping to the surface, as it tends to do under the action of the hydrostatic pressure, and also from passing through the underlying bed to lower layers. The sandstone, therefore, becomes a water-bearing stratum, and the water passes down the inclined plane between two impervious beds.

When this stratum is pierced by a well, the water rises, theoretically, to the level of the water column in the stratum (Fig. 26); that is, nearly to the level of the outcrop of the stratum at the point of entrance of the water into the earth. In reality the water does not rise so high, because of the

interference of friction. If, therefore, the outlet of the well is above the outcrop of the water-bearing stratum, the water rises only part way to the surface; but, if the outlet is below this, the water may gush out as a fountain, and such wells, artesian wells, are usually permanent and have a strong flow.

The slope of the stratum may be very gentle, in which case it may be tapped for great distances from its outcrop without boring to extreme depths; or it may be steep, and then an artesian well can be obtained only near the outcrop, unless it is driven to a great depth. Generally speaking, therefore, steeply dipping strata are not favourable to the construction of artesian wells.

It not infrequently happens that a series of strata, after having dipped at a certain angle for some distance, become horizontal, and then rise to the surface with an opposite dip, forming a syncline; and, if other conditions are favourable to the formation of artesian water-bearing strata, the centre of the syncline is a very promising place for an artesian well, since the hydrostatic pressure is maintained on two sides and the water supply comes from two outcrops, one on

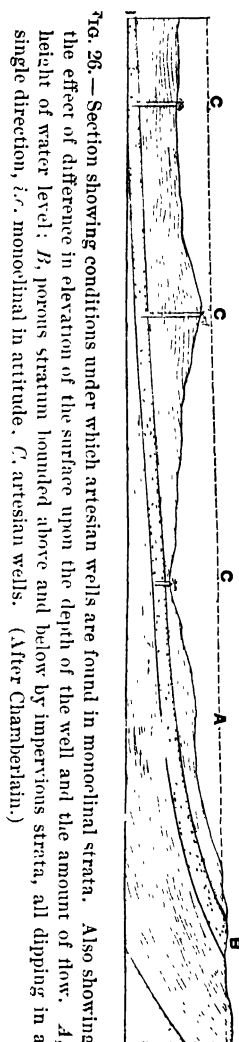


FIG. 26. — Section showing conditions under which artesian wells are found in monoclinical strata. Also showing the effect of difference in elevation of the surface upon the depth of the well and the amount of flow. *A*, height of water level; *B*, porous stratum bounded above and below by impervious strata, all dipping in a single direction, i.e. monoclinical in attitude. *C*, artesian wells. (After Chamberlain.)

either side of the syncline (Fig. 27). It is frequently stated that this is the normal condition for the formation of artesian wells; but such wells are much less common than those which are found in strata having a monoclinical attitude, or, in other words, a dip in only one direction.

From the above it will be seen that artesian wells are purely geological phenomena, and that a knowledge of the geology of a country will serve, not only to predict the

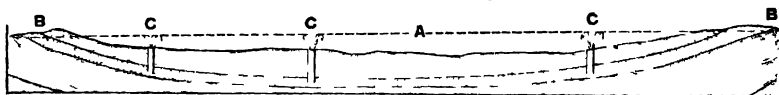


FIG. 27. — Section showing conditions under which artesian wells are found in a synclinal trough. *A*, height of water level, *B*, porous stratum, bounded above and below by impervious strata, and all folded into a syncline, *C*, artesian wells. (After Chamberlain.)

possibility of finding such supplies of water, but also the depth at which it will be found.

Even in moist climates artesian wells are frequently desired for a permanent supply of constantly flowing water; and, in regions of stratified rocks, they can usually be obtained with a force sufficient to cause the water to rise nearly, if not quite, to the surface. Not infrequently they are mineral bearing, and not suited for drinking purposes, but supplies of pure water are often obtained. The above principles of artesian-well occurrence are of value also in obtaining brine from salt-bearing strata, and, as has already been stated, the principles apply in part to the petroleum wells.

It is, however, in arid regions that artesian water is of most importance in this country, and every year this is becoming more true of these regions. There are large

tracts which, in their present condition, are absolutely unfitted for human habitation, or even for occupation by cattle, because there is no drinking-water. One does not need to travel very extensively in the arid regions to find large tracts where the wild grass has not been touched by the herds of cattle with which the more favourably situated parts of the region are overstocked. The rains come rarely, excepting in a small part of the summer season, and these either sink into the thirsty soil or flow away through channels which are usually dry.

The discovery of artesian water in such places opens up an otherwise inhospitable region to settlement. Even where cattle-raising is possible, agriculture is out of the question, because of the aridity and the absence of water for irrigation, the only supply being from scattered springs, with a small flow, near the mountains. In the mountains a sufficient amount of rain falls for some crops but the country is generally too rugged for cultivation, and the water, excepting from the larger ranges, does not escape beyond the margin of the mountainous tracts, being either evaporated or soaked into the ground. Since the mountain-forming rocks extend beneath the plains, artesian water may be found even where the surface is very arid. Moreover, on the less arid plateaus sufficient water falls, at certain seasons, to cause underground water-bearing strata. When these have been found at no great depth, large tracts which were formerly desert and uninhabited are now dotted with small farms irrigated with artesian water. One of the future possibilities of the arid regions consists in the discovery and development of artesian water-bearing belts, a work which is already begun, but hardly more than begun.

Mr. F. H. Newell¹ states that in the census year there were 8097 artesian wells in the western half of the country, 3930 of which were used for purposes of irrigation. California had 3210; Utah, 2524; Colorado, 596; Texas, 534; and South Dakota, 527 such wells. The average area irrigated per well was 13.21 acres, and in California and Colorado over 18 acres. The total number of acres thus irrigated was 51,896, of which 38,378 were in California. The total 8097 wells represent an investment of about \$1,988,461.

*Mineral Waters.*²

A very important industry in this country is the utilization of waters which, having dissolved certain mineral constituents from the rocks, issue from the earth either through natural channels, in the form of springs, or from artificially formed wells. These mineral waters possess some properties which render them of value for medicinal or other purposes. Peale, in the census report above referred to, classifies mineral waters as thermal and non-thermal, the latter being cold, and the former either tepid, warm, or hot. The thermal springs are generally, though not always, found in regions of recent or present volcanic activity, and are often one of the indications of this activity, — in this country one of the indications of dying volcanic action. All waters issuing from the earth contain mineral in solution; and it is this which gives to it medicinal qualities, chiefly that of a tonic. No such waters are more common than those containing

• ¹ Eleventh Census Bulletin, No. 193, *Artesian Wells for Irrigation*.

² A very valuable discussion and classification of the mineral waters in the United States, from which this summary is chiefly extracted, is found in the Eleventh Census Report, on *Mineral Industries*, pp. 779-787.

iron ; but there are numerous other kinds of mineral waters, such as those which contain sulphur, in the form of sulphuretted hydrogen, lithia, manganese, and many other substances. Many mineral springs are not utilized, and some which are used are of little value.

There are two classes of materials in mineral waters, gaseous and solid substances, although it frequently happens that both of these constituents are present in the same spring. It is upon the basis of the solid constituents that Peale constructs his classification, omitting the temperature, since there is every gradation from hot to cold springs, and since there is no necessary difference between the constituents of the two. Each group may be represented by thermal and non-thermal types, the term *thermal* being applied to those whose temperature is above 70° Fahr. The gaseous constituent is used for minor subdivisions.

This classification of mineral waters cannot be given here in detail, but in general the scheme is as follows: (1) Alkaline springs, when they contain carbonates, "whether of alkalies, alkaline earths, alkaline metals, or iron alone"; (2) alkaline saline springs, those in which carbonates are mixed with sulphates or chlorides; (3) saline springs; (4) acid springs, which include the sour water containing alum, sulphuric acid, etc. There are many subdivisions based upon this general scheme.

Some of these springs furnish water for bottling, while others are used entirely at the point of issue. It is difficult to obtain exact information concerning the number and value of the mineral springs of the country, but the following table gives the approximate statistics. In 1891 the list of commercial mineral springs in the country numbered 288.

PRODUCTION OF MINERAL WATERS IN THE UNITED
STATES, 1891.

STATES.	GALLONS.	VALUE.
New York	2,779,472	\$796,047
New Hampshire	960,000	502,000
Virginia	534,293	215,392
Wisconsin	2,882,117	184,133
Michigan	2,228,575	149,773
California	334,533	135,959
Colorado	481,038	133,222
Massachusetts	841,062	115,691
Total for the United States . .	18,392,732	\$2,996,259

It will be noticed that there is no necessary relation between the number of gallons produced and their value, since much depends upon the demand for particular classes of mineral water.

MINERAL-WATER PRODUCTION OF THE UNITED STATES.

YEAR.	GALLONS.	VALUE.
1880	2,000,000	\$500,000
1885	9,148,401	1,312,845
1891	18,392,732	2,996,259

The industry is thus a rapidly growing one. Our imports of natural mineral waters, in 1891, were 2,019,833 gallons, valued at \$392,894.

CHAPTER XVIII.

PRECIOUS STONES, ABRASIVE MATERIALS, SALT, MISCELLANEOUS MINERALS, AND GENERAL SUMMARY OF MINERAL PRODUCTION.

*Precious Stones.*¹

THE production of precious stones in this country has never attained especial prominence, although nearly all gems have been occasionally found. Turquoise and pearls are the only gems produced in this country in quantities sufficient to call for especial consideration; but, since there seems every reason to expect that valuable stones may yet be found in our western region, some mention will be made of these even though at present the production is unimportant. In prehistoric times turquoise was obtained by the Indians from Los Cerrillos, New Mexico, and beads of this mineral are often found with their implements. These turquoise veins are still worked, and recently other veins have been discovered in the Burro Mountains, Grant County, New Mexico, some of the gems from these mines being equal in colour to the best oriental turquoise.

During the present year (1893), turquoise has been discovered in the Jarilla Mountains, in Doña Ana County, New

¹ The subject of precious stones is treated fully by G. F. Kunz in *Gems and Precious Stones of North America*, by E. W. Streeter in *Precious Stones and Gems*, and also in the Eleventh Census Report on *Mineral Industries*, and the reports on the *Mineral Resources of the United States*, Day, U. S. Geol. Survey.

Mexico, and it is predicted that this will prove of great value. As in the case of the Grant County gems, the occurrence is in association with intrusive trachyte, the mineral being the result of an alteration of the kaolin which existed in the veins. The turquoise grew, as it were, in the kaolin, it being a hydrous phosphate of aluminum. All of these turquoise veins were originally worked by the Indians, and their discovery was due to this fact. But as an illustration of the lack of knowledge of the rarer minerals on the part of the prospectors, it may be pointed out that the Jailla deposit was overlooked on the assumption that it was a copper stain.

Pearls are frequently found in fresh-water clams belonging to the genus *Unio*, and some of these are of value. Particularly valuable finds have been made in Wisconsin, and Kunz states that pearls of good quality are more liable to be found in creeks which flow through a limestone country.

Precious stones, particularly sapphire and diamond, have been occasionally found in the gold-bearing gravels in various parts of the west, but, until very recently, no systematic efforts have been made to obtain them, nor has any success attended the efforts to find their source in the rocks. Recently systematic work has been carried on for the recovery of sapphire from the gravel bars in the Missouri River east of Helena, Montana. These are being carefully washed for gems, but only a small degree of success has rewarded the efforts, since the few gems which are found have not the red colour of ruby, nor the blue of sapphire, but range through lighter colours of blue, red, green, and yellow. Sapphire crystals have been found in an andesite dike crossing the slates upon which the gravels rest, and the source of the

gems may have been a similar rock, but no thoroughly scientific study has been made of the region and its possibilities. At Corundum Hill, North Carolina, some fairly good sapphires are occasionally found.

A few diamonds have been discovered in gravels in North Carolina, Georgia, and California, in well-defined areas, but they have not been traced to their source.

Garnets, valuable for gems, have been found in several parts of the country, but the principal supply comes from the Navajo Indian Reservation, where they are obtained from ant-hills. In 1890 opal was discovered in the state of Washington filling amygdaloidal cavities of varying size in basalt, and operations have been pushed with the result of producing some good-sized stones equalling those of Hungary and Australia. Tourmaline gems are found in the Colorado desert, Rumford, Maine, and elsewhere, and some very beautiful titanite or sphene crystals of a beautiful yellow colour have been obtained from the Tilly Foster mine in Putnam County, New York.

Quartz, either in the transparent condition, or coloured, or containing inclusions, is frequently used for cheap jewelry, and this industry is of considerable importance, particularly in places visited by numbers of tourists, such as the Hot Springs of Arkansas. In several parts of the west there are fossil forests in which petrified trees are composed of agate or jasper, often beautifully banded, and these are made use of extensively for the manufacture of ornaments and jewelry. Satin spar or fibrous gypsum is also cut into cheap ornaments and jewelry, and there are numerous other minerals used for similar purposes. Several gems, besides those above mentioned, have been found sparingly in the United States.

The following table furnishes an approximate statement of the value of the precious stone production of this country :—

PRODUCTION OF PRECIOUS STONES IN THE UNITED STATES.

STONES.	1884.	1886.	1888.	1890.	1891.
Turquoise	\$2,000	\$3,000	\$3,000	\$28,075	\$150,000
Sapphire	1,750	750	500	6,725	10,000
Quartz	11,500	11,500	11,150	14,000	10,000
Gold quartz	140,000	40,000	75,000	9,000	6,000
Smoky quartz	12,000	7,000	4,000	2,225	5,000
Opal . . . . .	....	....	....	....	5,000
Catlinite	10,000	10,000	5,000	5,000	5,000
Garnet	4,000	3,250	3,500	2,308	3,000
Tourmaline	2,000	5,500	....	2,250	3,000
Agatized wood . . . . .	....	....	....	6,000	2,000
Diamond	800	60	....	....	....
Total	\$222,825	\$118,850	\$139,850	\$118,833	\$235,300

The above table, which is in large part merely a rough estimate, probably does not represent the true value of the output of gems and precious stones, since large quantities are sold at the point of production, and cut by local jewellers, without any record being kept. Moreover, there are many mineral collectors who purchase precious stones for private and public collections, some of them purchasing the entire output of some of the smaller producing localities. It is not improbable that the true value of the industry is fully double that stated in the above table, but, nevertheless, the precious stone production of the United States is extremely limited, and the country is probably by no means up to its possible

capacity as a producer of these minerals. Now that the west has entered upon a stage of more minute and intelligent exploration, it need not be surprising if gems of value are found. When we compare our precious stone production with our consumption of cut and uncut gems, which in 1891 was valued at over \$12,700,000, and with the output of diamonds from the Cape of Good Hope fields, which in 1890 *exported* £4,162,073 sterling worth, we plainly see the lack of importance of the United States in this respect.

Abrasive Materials.

General Statement.—There are two classes of materials which serve for abrasive purposes: those used as a powder or a sand, and those used as stones. In the first class are grouped sand, diamond, corundum, emery, infusorial earth, and some minor substances; and, in the second class, millstones, grindstones, and whetstones. Sometimes stone of the latter class are prepared artificially, by the manufacture of a rock consisting in part of powdered or granular abrasive substances; but more commonly they are naturally formed rocks. Sand is used for abrasive purposes in polishing and sawing certain stones, such as marble, the sand being fed to a straight-edged steel saw, which moves back and forth on the stone, and uses the sand for cutting edges. Diamond dust, obtained from the waste made in cutting diamonds, and from black and imperfect diamond bort, is also used for sawing hard rocks and minerals, chiefly in the preparation of gems and the manufacture of ornaments from hard rocks and minerals. Being the hardest known mineral, it is of great value for these purposes. Corundum and emery are used, in the form of granular fragments, and as a fine flour-like powder, for

smoothing and polishing purposes, as, for instance, in polishing granite and other rocks, and also in the form of artificially made wheels for grinding purposes. Infusorial earth is also used for polishing, but for a finer grade of work than the above materials.

Infusorial Earth.—Certain animals, known as Infusoria, and plants belonging to the group of Diatoms, secrete shells or tests of silica, and when they die these durable parts are left behind. When in particular bodies of water these organisms are the predominant forms of life; having durable shells they tend to accumulate in beds, forming diatomaceous or infusorial earth. These forms of life are particularly abundant in fresh-water ponds; and consequently their remains are commonly found in the swamps, which are filled-up lakes, of the glacial belt in New England and other northern states. Where these ponds were small, and their banks bordered with reeds and other forms of vegetation, very little sediment entered, and the accumulations were principally organic, and the infusorial beds comparatively pure. A thin layer of this white, powdery earth is found in excavations in many swamps, but it is usually not sufficiently abundant to be of value. Infusorial earth, in this country, is principally obtained from Pope's Creek, Maryland, but California, New Hampshire, and New Jersey also produce some. There is not an extensive demand for this substance, and consequently the output is limited. It has served, as an absorbent, in the manufacture of dynamite; but wood pulp is replacing it for this purpose. In the form of a soap or a powder, it is used as silver polish and for other cleansing purposes, and also in the formation of a glaze for bricks.

Corundum and Emery.—These minerals differ from each other very slightly, the former being oxide of aluminum, and the latter being corundum mixed with iron oxide. The former is, therefore, harder and more durable, and hence more valuable, it being the hardest of the minerals which are common enough for extensive use, ranking next to diamond in the mineralogical scale of hardness, diamond being 10, corundum 9 (in its pure form sapphire). Emery is found in the metamorphic rocks at Chester, Massachusetts; and corundum is produced at Laurel Creek in Georgia and Corundum Hill in North Carolina. It occurs here at the contact of gneiss and serpentine, the latter having resulted from the alteration of an olivine rock. There are other minor localities for these minerals. Practically all of the corundum used in the country is of domestic production, but much of the emery is imported, our imports in 1891 having amounted to \$104,199.

Grindstones and Buhrstone.—Grindstones are made of a firm, gritty sandstone, and these are principally produced from the Berea grit of Ohio and Michigan, although California and South Dakota also produce some. Although some of the grindstones used in this country are imported, the greater number are of domestic production.

The industry of buhrstone or millstone production has rapidly decreased since the introduction of the roller process of grinding grain, but they are still used in many of the small grist mills, and for grinding cement, paint, gypsum, etc. Stones for these purposes are found in this country; but the grist mills still using buhrstones prefer the French buhr, which is of superior quality to any produced in this country. A buhrstone must be fine grained and very com-

pact, much more so than grindstones; but it must not glaze too readily, nor, on the other hand, should its texture be so loose that particles rub off, as in the case of grindstones. A gritty quartzite or a quartz conglomerate are the rocks best adapted for this purpose; and in this country the chief supply comes from Ulster County, New York, and, in smaller quantities, from Pennsylvania and Virginia. In 1891 we imported \$24,039 worth of millstones.

Oilstones and Whetstones. — Oilstones and whetstones are chiefly of domestic production. Since 1823 New Hampshire has been the seat of the scythe-stone industry, a valuable grit for this purpose being found in a mica schist in Grafton County. Whetstones are also found in Massachusetts and Vermont. The western grindstone grits furnish some scythe-stones; but they are more gritty and coarser, and hence inferior to those produced by the New Hampshire company, which also operates the Massachusetts and Vermont quarries, and exports considerable quantities to Europe.

Oilstones are of a still finer texture, and these are also found in New Hampshire; but the most important seat of the oilstone production is in Garland County, Arkansas, where there are extensive beds of novaculite, of Palæozoic age, occurring stratified with shales and limestones in very much folded strata. These deposits were first made to produce commercially in 1840, although extensive quarries were worked for implements by the aborigines. These stones, known as Washita and Arkansas oilstones, are recognized as the best in the world for sharpening fine tools, and they are extensively used for this purpose both in Europe and the United States. The most important quarries are situated near the Arkansas Hot Springs, and

Griswold states¹ that they are actually deposited sediments of fine-grained quartz, instead of a chemically precipitated deposit, as was formerly believed. There are immense quantities of novaculite in this region, but the grade is very variable, and some of it is quite inaccessible at present.

An oilstone, known as the Hindostan, is quarried in Orange County, Indiana. It is a very compact sandstone, and, although very good, does not equal the Arkansas novaculite; but is more cheaply quarried and fashioned, and hence is sold at a lower price. A more coarsely grained sandstone, known as the Shoemakers' sandstone, is also obtained from Indiana, and, until recently, this has been of considerable value in shoemaking; but the introduction of improved machinery has caused the demand to rapidly decrease.

Statistics.—In 1891 this country exported \$51,500 worth of whetstones, and the following table shows the production of the various abrasive materials for a series of years:—

PRODUCTION OF ABRASIVE MATERIALS IN THE UNITED STATES.

MATERIALS.	1880.	1885.	1890.	'92.
Infusorial earth.	\$45,660	\$5,000	\$50,240	\$20,000
Corundum and emery	29,280	108,000	89,395	88,000
Grindstones	500,000	500,000	450,000	500,000
Bulrstones	200,000	100,000	23,720	16,000
Whetstones and oilstones,	8,000	15,000	69,909	150,000
Total	\$782,940	\$728,000	\$683,264	\$774,000

¹ The novaculite of this country, and the industry in general, are fully described by L. S. Griswold in a valuable Monograph entitled *Whetstones and Novaculites of Arkansas*, Ann. Rept. Ark. Geol. Survey for 1890, Vol. III.

Salt.

Our supply of salt comes either from brine or from deposits of rock-salt. At several places in California salt is obtained by evaporating ocean water; but this source is not as important as might at first be supposed, since more concentrated solutions occur elsewhere. In various parts of the Cordilleras salt lakes exist, and there is every gradation in this region, from fresh-water lakes to deposits of rock-salt, which have resulted from the evaporation of salt lakes. There are several salt works located upon the shores of Great Salt Lake, in Utah, and in Nevada, upon the shores of the smaller salt lakes of that state. The salt thus obtained by solar evaporation is used principally for local purposes, particularly in the chlorination process of reducing ores. Some of these lakes have crusts of salt, and, in some cases, in all the arid regions of the west, the water has entirely disappeared under the influence of the arid climate, and here the ranchmen are able to obtain their supply of salt at the surface, from beds of rock-salt produced by the natural evaporation of dead seas.

Rock-salt deposits, now buried in the earth, have resulted from the same process as that just described, and these are found stratified in rocks of various ages from the Silurian to the present. Water, in its passage over and through the earth, dissolves many minerals, the most common being salt.¹ When these waters, which contain so little salt that they seem fresh, enter an enclosed sea without an outlet, the fresh water is evaporated and the salt is concentrated, until, finally, after a long period of time, it may accumu-

¹ The mineralogical name of salt is halite.

late in a solid mass of rock-salt either at the bottom of the lake, or in place of the lake, if all of the water is evaporated. Many impurities usually occur with rock-salt, either disseminated through it or concentrated into layers. These represent the impurities dissolved in water with the salt. Other chlorides, particularly those of calcium and potassium, gypsum, iron, and sedimentary deposits of clay or sandstone, are some of the common impurities which must be separated.

A bed of rock-salt of considerable extent occurs in the Tertiary deposits on Petit Anse island in Louisiana, where it was discovered, during the Civil War, beneath the site of some salt wells which had been known for a long time. In western New York beds of rock-salt occur in the Silurian over a wide area, in Kansas in the Triassic, and in Texas in the Permian rocks. Some of these rock-salt deposits are actually mined, but some are worked as brines, water being allowed to enter the salt beds from below, through artificial borings; and, after dissolving the salt, the water is brought to the surface either through natural artesian wells or by pumps. Some of these beds are undoubtedly dried-up salt lakes, but some may be salt deposits which have accumulated in shallow coastal lagoons or upon salt marshes along some ancient shore.

However, much of the salt of the country is made from natural brines which occur scattered through rocks of all ages, and are obtained from wells, either by pumping or as artesian water. The most common mode of occurrence is in beds of sandstone, capped and underlain by more impervious beds. Some of this salt may have been originally built into the rocks when they were deposited in the ocean; some may

represent beds of rock-salt subsequently dissolved; and some are apparently derived in the same manner as petroleum and natural gas,—namely, by accumulation in a porous stratum from some outside source. Associated with the salt in the brine are the same minerals which are found in rock-salt; and brines are also frequently associated with petroleum and natural gas. Some of the impurities, such as gypsum, are injurious; and one of the chief problems in salt manufacture is how to remove all of these substances without injuring the salt or interfering with its evaporation.

Our salt supply comes chiefly from the Salina group of the Silurian in New York and from the Carboniferous in Michigan; but other states and other ages of rocks are also saliferous. The salt is obtained in some places by solar evaporation, in large shallow pans; in others, by artificial heat obtained by burning wood, coal, or natural gas. The price of this mineral is extremely low, and it is produced at a profit only where it can be obtained very easily and evaporated cheaply. This is very strikingly shown by the fact that sea water can rarely be evaporated, even in arid regions, and made to yield salt at a profit. Nevertheless, both in this country and in Europe this is done in certain very favourably situated localities.

The distribution of the salt supply is shown in the following table; but this does not represent the distribution of salt, for there is probably vastly more in the Tertiary and recent strata of the Cordilleras than in any other part of the country, but it is too far from the market to be of value. Very pure salt can be obtained by the wagon-load in scores of places in the far West.

PRODUCTION OF SALT IN THE UNITED STATES.

STATES.	1883.	1885.	1887.	1889.	1892.
New York . .	\$680,638	\$874,258	\$936,894	\$1,136,503	\$2,200,000
Michigan . .	2,344,684	2,967,663	2,291,842	2,088,909	1,906,027
Kansas . . .	....	....	....	202,500	698,395
Utah	100,000	75,000	102,375	60,000	295,000
Ohio	231,000	199,450	219,000	162,500	276,000
West Virginia,	211,000	145,070	135,000	130,000	166,800
California . .	150,000	160,000	140,000	63,000	125,000
Louisiana . .	141,125	139,911	118,735	152,000	81,000
Total . . .	\$4,251,042	\$4,825,315	\$4,093,846	\$4,195,412	\$5,879,222

New York has rapidly increased its output, and Kansas has shown a remarkable increase since 1888, when salt first began to be produced there. At the same time, Louisiana and Michigan have decreased; and in ten years there has been a very slight total increase for the country. Our production of salt is practically what we consume, although we export about \$30,000 worth a year; and in 1892 we imported \$768,734 worth, chiefly for special purposes. The output for 1892 represents 11,585,734 barrels of 280 pounds each. Aside from a certain increase in demand for this mineral in the reduction of ores and in the manufacture of caustic and baking soda, the increase in the salt industry must be dependent upon the increase in population, its consumption for cooking, table, and curing purposes being the most important uses of the mineral.

OUTPUT OF SALT IN THE WORLD, 1891.

METRIC TONS (2204 LBS.).

Great Britain	2,077,072
Russia	1,400,000 ¹
United States	1,300,107
Germany	666,793
Spain	225,870 ²
Hungary	159,898
Canada	45,021
Italy	31,285
Colombia	21,044

Bromine.

This element is not found free, but in the form of bromides, and the chief source is from rock-salt and salt water. It is produced as a by-product in the manufacture of salt in West Virginia, Michigan, and some other salt regions. During the evaporation of salt, it becomes concentrated, together with some other substances, in the bittern or mother liquor, from which it is extracted. Its chief use is for chemicals, in the manufacture of an aniline colour (eosene) and, in smaller amounts, as a disinfectant. In the past twelve years the product of bromine in this country has varied somewhat; but in 1892, 379,480 pounds were produced, valued at \$64,512.

Borax.

Among the other substances found associated with salt are borax, soda, and gypsum, the latter of which is described in the preceding chapter. Borax exists in the alkaline flats of the arid regions which contain valuable stores of alkaline

¹ Estimated.² Exported

substances, the greater part of which no attempt has ever been made to utilize. In Tuscany this substance occurs in hot springs, while in Hungary it is obtained from the rock-salt; but in our country the source is the beds of desiccated lakes in the desert regions of Nevada and California. The "salines," which contain borax, in the west, probably received their supply from hot springs resulting from the neighbouring volcanic activity which was very well developed in the Great Basin during the period of desiccation. The minerals are borate of soda and of lime, mixed with clay, gypsum, salt, and other impurities. There is also borax in fissure veins in California, probably deposited in the tube of a hot spring similar to the Tuscan springs; and the industry of borax production in that state has rapidly increased since the introduction of deep mining. Aside from the European localities, borax is produced also in Thibet, Asia Minor, and Chili, in dried lake bottoms similar to those of the Great Basin of the Cordilleras.

The original source of borax is probably in all cases volcanic emanations, the hot springs of Tuscany illustrating the active stage in its production. These, flowing into the waters of the salt lakes, caused borax to accumulate in the same manner that salt and gypsum accumulate in the same places. In the west the borax permeates the soil, as does ordinary alkali; and in favourable situations, a crust forms upon the surface. After this has been removed, a new deposit commences to form by the solution of the mineral in percolating waters; and its rise to the surface by capillary action forms a crust by the subsequent evaporation of the boracic waters. After five or six years a new crust is formed; but this naturally does not equal, in thickness, the

original crust which has been accumulating for ages. It is removed, dissolved, and evaporated; and the process is repeated until crystals of nearly pure borax are formed.

Borax is used in welding, since it forms fusible salts with most metallic oxides, and it is also used in glazing brick, chinaware, etc., as well as in the manufacture of enamel for ironware, and for the gloss given to starched linen in laundry work. As an antiseptic it is important, and it is also used in dyeing, for sanitary purposes, and in drugs. Our consumption of borax about equals the production, which is given in the following table:—

PRODUCTION OF BORAX IN THE UNITED STATES.

POUNDS.

YEAR.	CALIFORNIA	NEVADA.	TOTAL.
1864	24,304	....	24,304
1865	251,092	.	251,092
1875	2,336,000	2,804,000	5,140,000
1880	1,219,948	2,640,800	3,860,748
1885	1,885,300	5,586,104	7,471,404
1890	6,402,034	5,487,794	11,889,828
1892	11,596,574	2,646,525	14,243,099

Since 1864 the total production of the United States has been 128,539,190 pounds, and the price has steadily decreased, with some fluctuations, having remained, however, for the past four years $7\frac{1}{2}$ cents a pound in New York. The value of the borax output at the place of production was, in 1892, \$925,810.

Natural Soda.

This is obtained from the alkaline substances which are so abundant in arid regions, such as those of the Great Basin, the deserts of Africa, Asia, and South America, where it occurs in the form of carbonate and bicarbonate of soda mixed with clay and various chemical impurities. The alkali coats large areas with a snow-white, efflorescent deposit, and sometimes with a thick crust. There are vast quantities of these substances in the deserts, alkali flats, and alkaline pools of the west; but as yet little has been done to extract them, and only a small amount is produced. This is probably an industry which will assume marked importance in the future, now that the knowledge of methods of extraction has improved and means of cheap transportation are at hand.

Magnesite.

This mineral, which is a carbonate of magnesia, occurs in a number of places in California, and possibly elsewhere in the Cordilleras. It resembles unglazed porcelain, being hard, fine grained, and white. There are several modes of occurrence, one being in a vein from five to seven feet thick in Childs Valley, while elsewhere it is generally bedded with talcose slates, serpentines, and magnesian carbonates or dolomites. Until recently no use has been made of this mineral, but within a few years experiments have been made with the idea of introducing it; and already it is being used as a substitute for chlorine, as a bleacher, in the manufacture of paper from wood pulp, for which purpose it is said to be better suited, as well as cheaper, than chlorine. Other uses are also made of it, and it is expected that it will be possible

to ship the mineral as far east as Pittsburg and compete with the foreign magnesia used in the manufacture of basic steel.

Sulphur.

Sulphur is obtained from three sources,—iron pyrite, which has already been described,¹ from the waste calcium sulphic produced in the alkali works, and from native sulphur. Native sulphur is known to exist in various parts of the west, but nearly all of these deposits are so inaccessible, and the cost of transportation to the market so great, that they are not exploited. At present the total supply produced in this country comes from Utah and Nevada. Outside of the United States sulphur is found in numerous places, chiefly in volcanic regions. Extensive deposits are known to exist in Japan, but they are not favourably situated for profitable production, and our principal supply comes from the island of Sicily, which has produced this mineral for several centuries. It is obtained here from various mines, scattered over a wide area, and worked to a considerable depth by very crude and antique methods. Since 1831 there has been produced from this district nearly 13,000,000 tons of sulphur, valued at not far from \$350,000,000.

At first thought the explanation of the origin of sulphur seems simple, particularly when it occurs in volcanic regions, where emanations of sulphur vapor are commonly associated with eruptions of lava. Since sulphur deposits are so commonly associated with recent volcanic rocks, there is good reason to believe that they are frequently the result of this association. But the breaking up of sulphuretted

¹ p. 300.

hydrogen, produced from the decomposition of gypsum or of organic remains, will also form sulphur deposits, and such appears to be the origin of at least some of the Sicilian sulphur and of a bed of sulphur which occurs stratified with sedimentary rocks in a region no less remote from volcanoes than western Louisiana.

The demand for native sulphur is decreasing, although the uses to which it is put are increasing. This is due to the increasing use of pyrites in the manufacture of sulphuric acid, and to the production of sulphur from the calcium sulphide, which was formerly a waste product in the manufacture of alkalies. The statistics of the production of iron pyrite are given in a previous chapter.

We have in this industry the rather anomalous condition of abundant supplies at home, but practically no home production, notwithstanding a heavy demand for brimstone at a price varying from \$22 to \$30 a ton. There are other minerals of minor importance which illustrate the same peculiarity; but in most cases where our mineral supply is good our production is large. These peculiarities are generally, as in the present instance, the result of a failure of railroad transportation to compete with ocean transportation, combined with certain difficulties of mining and transporting materials in our sparsely settled western territory. There are some reasons to hope that the sulphur deposits of the west will eventually become of importance, but at present only those of Utah are of value.

Sulphur is used in the manufacture of sulphuric acid, matches, gunpowder, and many minor substances, as well as in its native condition in medicine and for other purposes. In 1892 our production of this mineral amounted to 1825 short

tons, valued at \$54,750, while we imported, chiefly from Sicily, 100,711 long tons, valued at \$2,189,307. During 1890 Sicily exported 344,763 tons, and during 1891, 293,323 tons.

Fluorite.

This mineral is not uncommon, as a veinstone, in various parts of the world, and it is found sparingly in granites and metamorphic rocks; but until within a few years it has not been considered of much value. Now, however, it is introduced into the reduction of some of the refractory ores, for which it serves as an excellent flux; and it is also used in the manufacture of opalescent glass, in the production of hydrofluoric acid, and for other minor purposes. In this country the only source of fluorite is the galena-bearing limestones at Rosiclare, Hardin County, in the southern part of Illinois. Formerly these deposits were worked for lead, and the fluorite was a waste product, but now the reverse is true. The mineral occurs in true fissure veins, which have been traced for a distance of several miles. Fluorite is not an uncommon mineral in altered dolomitic limestone, and it is possible that the above deposits will change in character when the limestones are passed through.

The output of fluorite from this region has more than doubled in the past ten years, and in 1892 amounted to 9000 short tons, valued at \$54,000. No fluor-spar is imported, but it is obtained as a by-product in the reduction of cryolite to aluminum and sodium. This source is decreasing, however, with the introduction of bauxite as a source of aluminum. In 1892, 8155 long tons of cryolite, valued at \$73,847, were imported into this country.

Graphite.

Plumbago, or graphite, one of the pure forms of carbon, occurs in metamorphic rocks, particularly in limestones, where it is undoubtedly the result of the metamorphism of carbonaceous substances of organic origin. The same is true of the graphitic coals of Rhode Island, where the Carboniferous coal has been metamorphosed almost to the stage of graphite, and locally actually to this condition. The Rhode Island graphitic anthracites are used to some extent in the manufacture of crucibles and stove-blackening. Graphite has also been mined in Pennsylvania, New Jersey, Michigan, and Wyoming; but the only important American source of this mineral is at Ticonderoga, New York, where, in the metamorphic rocks, there is a vein of sufficient purity to be used in the manufacture of lead-pencils. This mineral is found in Japan, Russia, Canada, Germany, Austria, and Ceylon, the bulk of our supply coming from the latter region. In every case the source being rocks of metamorphic origin, this fact has led some to hold that for this reason we must consider them to be of sedimentary origin and the graphite to be inorganic in origin; but this is mere assumption.

In 1891 the output of graphite in the United States was 1,559,674 pounds, valued at \$110,000, and in the same year we imported \$555,080 worth of plumbago. The better qualities of graphite are used in the manufacture of lead-pencils, and much is also used in the preparation of lubricants, while the poorer qualities are manufactured into stove polish, crucibles, paint for the protection of iron, and other similar purposes.

Lithographic Stone.

Although this country imports about \$100,000 worth of unengraved lithographic stone each year, none is produced here. This is probably not because there is none in the country, but rather because its occurrence has not been detected. There are, in many places, rocks which very closely resemble lithographic stone, but these have not the fineness of quality which fits the Solenhofen stone so well for lithographic purposes. This is a compact, homogenous, fine-grained limestone, of gray or creamish colour, found at Solenhofen in Germany. It varies somewhat in texture, and colour, and some is suited only to low-grade work. Lithographic stone is found elsewhere in Europe, but in no case is the quality equal to the German stone. In Texas there is a stratum which is apparently a good quality of lithographic stone, but it is cut by joint planes, which prevent its extraction in good-sized blocks. Below the surface this may be found to be less jointed, but the deposit has been scarcely prospected. Beds of this stone are also reported to occur in Virginia, Indiana, and Arkansas, but nothing can be said at present concerning their value. It seems very improbable that, among all the varieties of rock, of all ages and all kinds of origin, occurring in the west, this particular kind should be absent; and the most probable explanation of our non-production is ignorance of its character by the prospectors who have explored the region.

Mica.

The group of micas, which includes a great variety of minerals, all of which are complex silicates of alumina, with

varying proportions of iron, sodium, potassium, magnesium, etc., is one of the most common groups of minerals, being present in the greater number of metamorphic, many igneous, and some sedimentary rocks. It is, however, of value only when found in considerable quantities, in the form of large sheets; and these occurrences are relatively rare. The two varieties, biotite and muscovite, are of commercial importance, the former being only semi-transparent in thin sheets, while the latter is quite transparent. Large sheets of these minerals are found, usually in coarse pegmatite veins in granite, in coarse granite, and in thin beds in metamorphic rocks.

Mica is obtained from several places in New Hampshire, but chiefly from the Palermo mine in Grafton County, which produces nearly all the supply obtained in this country. Small quantities also come from North Carolina, and a very little from South Dakota and Wyoming. In the table at the close of this section it will be noticed that, since 1884, there has been a marked falling-off in the output of the country. This is due to the importation of a very fine grade of mica from India, where it occurs in extensive deposits which can be so easily worked and so cheaply produced that, even with a duty of 35 per cent *ad valorem* and the long distance of transportation, it can compete with the mica produced at home.

Recently Canada has begun to produce mica in great quantities; and the mineral, although biotite, and therefore not transparent, can be used for various purposes where transparency is not necessary. This biotite is obtained chiefly in Ottawa from the apatite mines, and the industry is succeeding that of apatite production which has been seriously

checked by the important discoveries of phosphates in the United States.

During the process of mining, the mica is obtained in as large pieces as possible; and it is afterward cut into sheet mica, provided the quality is sufficiently good. For this purpose, either wine colour or white is desired, and the sheets must be smooth and free from spots.

The price varies according to the size; but of late years there has been an increasing demand for the smaller sizes, since the industry in which it is chiefly employed (panels of stove and furnace doors) now makes use of numerous small sheets instead of one large sheet. Sheet mica is also used extensively in electrical apparatus; and since colour is not important, the dark biotites of Canada are being used for this purpose. This class of mica must be flexible and non-conductive, and the sheets must be of uniform size, although many different sizes are made. There is also a rapidly increasing demand for ground mica, which is made of the scraps and waste produced in the manufacture of sheet mica. One of the most important uses of this material is for the production of the frosted and spangled effect in wall papers, and the finer grades of ground mica are used for metallic white surfaces. Ground mica is also used in the manufacture of lubricants for car and carriage wheels.

The production of mica in this country is shown in the following table. Of the output for 1892, New Hampshire produced, approximately, \$70,000; North Carolina, \$25,000; and the other \$5000 was distributed between several states. The imports come chiefly from India and Canada.

PRODUCTION AND IMPORTS OF MICA IN THE UNITED STATES.

YEAR.	POUNDS.	VALUE.	IMPORTS.
1880	81,669	\$127,825	\$12,562
1884	147,410	368,525	27,555
1890	60,000	75,000	146,975
1892	75,000	100,000	100,846

The waste and scrap material made into ground mica is not included in the above table. In 1892 it amounted to 959,000 pounds, valued at \$67,130.

Talc and Soapstone.

A series of minerals of different varieties, but possessing the same general character, are included in this group. They are hydrated silicates of magnesia, and are soft, with a soapy feeling, a colour usually grayish or greenish, and a greasy lustre. Some, such as fibrous talc, bear a certain resemblance to asbestos; and they are all characterized by their slight expansion during changes of temperature, which adapts them to certain particular uses. In an impure state they are common in metamorphic rocks, often in sufficient quantities to produce talcose schists; and among these, beds of sufficient purity for commercial purposes are sometimes found. Nearly every state in the Union where metamorphic rocks occur has talc deposits; but only a very few produce it. Steatite, or soapstone, is the most common form, and this is found in the metamorphic rocks of Pennsylvania, New Hampshire, New Jersey, Virginia, Vermont, and Maryland, but

principally in the two first states. Fibrous talc is mined near Gouverneur, New York, but some comes also from Fairfax County, Virginia.

Soapstone is obtained from quarries; and the large blocks are trimmed into slabs to be used for various purposes, such as hearths, mantels, fire-bricks, linings to stoves, laundry, bath, and acid tubs, etc. Aside from its slight expansion and contraction under changes of temperature, soapstone does not absorb acid or grease, and this makes it valuable for some of the above purposes. The smaller fragments are made into smaller articles, such as slate-pencils and ornaments. Ground into a powder, it is used as an adulterant of soap, paper, rubber, etc.; and owing to its extreme fineness of grain, it is valuable for paint, particularly that used for the protection of metal, since it not only adheres closely, but also resists the attacks of acids and solvents. Steatite grease is used as a lubricant, and there are many similar uses for the mineral. The aborigines quarried soapstone extensively for the manufacture of ornaments and pipes, these being easily fashioned because of the softness of the rock.

The fibrous talc produced at Gouverneur, New York, is entirely ground to a powder, and used chiefly as a filler of medium quality paper and for increasing its weight. For the purpose of a filler, it is superior to clay, since it is fibrous and makes the paper stronger. It is also used as an adulterant of soap and of many white powdery substances.

In 1889, 12,715 short tons of soapstone were produced in the United States, and of this 4371 tons came from Pennsylvania, 4250 tons from New Hampshire, 1500 tons from New Jersey, and 1300 tons from Vermont. The production of talc and soapstone in the United States is shown

in the following table, in which it will be seen that the industry is a rapidly growing one:—

PRODUCTION OF TALC AND SOAPSTONE IN THE UNITED STATES.

YEAR.	FIBROUS TALC.		SOAPSTONE.	
	Short Tons.	Value.	Short Tons.	Value.
1880	4,210	\$57,730	8,441	\$66,665
1885	10,000	110,000	10,000	200,000
1892	51,000	459,000	19,000	266,000

Asbestos.

There are two species of minerals which have a fibrous habit and marked resistance to heat,—one asbestos, a variety of hornblende, the other chrysotile, a variety of serpentine, and both called asbestos in the market. The first occurs in metamorphic rocks rich in the varieties of hornblende, the second is found in serpentines which have commonly resulted from the alteration of olivine-bearing rocks. Both are equally valuable for their power of resisting heat, but asbestos is inferior in strength and is not used where great strength is required.

There are no deposits of chrysotile which are worked in this country, but asbestos is found in a belt of metamorphic rocks on the eastern slope of the Appalachians from New York to Georgia. Limited amounts have been produced from here, but the principal source of asbestos in this country is California, although some occurs also in Wyoming. During 1891 this mineral was reported from

several parts of the Cordilleras, and a company was organized for its production in Gallatin County, Montana.

The output of asbestos in this country has steadily decreased, and, in 1891, only 66 tons, valued at \$3960, were produced. Our supply comes almost entirely from Canada, which, since 1879, has become an important producer of chrysotile, the market having previously been supplied from Italy. The Italian asbestos has long fibres and is well suited to weaving. The Canadian chrysotile comes from the serpentine belt of the province of Quebec south of the St. Lawrence. Our imports of asbestos for 1891 were valued at \$358,461; and as these are rapidly increasing, it will be seen that the discovery of extensive deposits of this substance in this country is very desirable. In 1891 Canada produced 9279 short tons of asbestos, valued at \$999,878. This mineral is used for fire-proof mineral cloth and paper, fire-proof paints, linings of fire-proof safes, for packing, for covering boilers, and for numerous purposes where fire-proof qualities are desired.

Barite.

This mineral, the sulphate of barium, also called barytes and heavy spar, is a common veinstone and is remarkable for its great weight. The chief commercial source in this country is from veins and pockets in limestones, principally from Missouri and Virginia, the work of extraction in the former state being done at intervals by farmers. Barite must be free from quartz-grains, which make the powder gritty, and from iron stains, which injure its normal white colour, although it may be made white by boiling in sulphuric acid and thus removing the iron stain.

Barytes is used as a pigment and as an adulterant for white lead, which it closely resembles in colour and weight, and for other purposes of adulteration. Its great weight and white colour make it valuable for these purposes, and it is said that it does not injure the quality of white lead. It is not distinctly injurious in other forms of adulteration. The United States produced, in 1891, 34,796 short tons of barite, valued at \$118,363, and our imports of manufactured barium sulphate were valued at \$22,458, and of the unmanufactured barite, \$8816. Of our output, in 1891, Missouri produced \$60,000 worth; Virginia, \$52,765; and the balance, \$5688 worth, came from North and South Carolina.

Mineral Paints.

Various mineral products, clays, minerals themselves, and compounds manufactured from them, are made use of in the manufacture of paint. Already chromium and cobalt ores have been considered, and, in the discussion of lead, it was stated that one of the most important uses of the metal was the production of white lead, which is of so much value in paint manufacture. In 1891 the white lead product was 78,018 short tons, valued at \$10,454,02. The use of barite as an adulterant and the manufacture of zinc-white as a substitute for white lead have been referred to in previous pages. The value of the zinc-white produced in 1891 was \$1,600,000. Red lead and litharge are also made artificially, the value of the red lead production in 1891 being \$591,730, and of litharge \$720,925. Several metallic paints are also manufactured, and many colouring substances are made by chemical processes; but the consideration of these scarcely comes within the scope of this work.

Natural metallic paint is made from the coloured clay which is sometimes produced by the decay of mineral veins, — copper producing green; iron, red and yellow earths, etc. Dark red and brown paints of this nature are mined in Pennsylvania, New York, and elsewhere. In 1891, 25,142 short tons of such paint, valued at \$334,455, were produced. The production of ochre is also an important industry, and, even by the aborigines, clays coloured bright red and reddish yellow by iron peroxide were used as pigments. There are large deposits of such clays, and they are mined, finely ground, and then mixed in paints, giving both colour and body to them. In this industry Pennsylvania ranks first, but Virginia and Missouri also produce considerable quantities. During 1891 the output of 18,294 short tons of ochre was valued at \$233,823.

General Summary of Mineral Production.

The mineral industry of the United States deserves to rank among the most important of our industries. In 1892 approximately \$670,000,000 worth of mineral products were won from the earth, this estimate for most of the minerals representing the value of the product at the mines. The materials thus won serve as the basis for a vast series of manufacturing industries and for a vast amount of exchange. In the industry of producing these materials, and in those industries which are dependent for existence upon the supplies of mineral products, a very considerable percentage of our population is employed. Indeed, it would be difficult to imagine the condition of the nation if these supplies were not at hand.

Even more difficult is it to estimate the importance of

these mineral industries in aiding the growth of the nation and our remarkable industrial progress. There are two great primary industries, — the one supplying food and certain products for manufacture, directly or indirectly from agricultural supplies; the other, the extraction of substances from the earth and the manufacture of materials from them. In both of these industries the United States holds a high rank; but, while there may be other nations which equal our agricultural industry, there are none which approach us in mineral resources. For the highest industrial development both of these industries should go hand in hand, and this is the case in the United States.

While it may be said that industrial progress is largely dependent upon mineral resources, it is equally true that, for the highest development of these resources, a certain measure of progress in industry is first necessary, in the present state of our civilization. Thus it is that the mineral resources of the United States are, with the exception of certain precious and valuable metals and a few minor substances, developed chiefly in the eastern states. This is even more marked when the whole world is considered; for the industry of mineral production of Europe and the United States far exceeds that of all the rest of the world. This is partly due to lack of exploration, cost of transportation, sparseness of population, and other similar causes; but it is also, in large part, due to the small degree of industrial progress. Why, for instance, do Mexico and the South American nations depend upon the European and American markets for so many products of the mineral industry? Certainly not for lack of opportunities. Japan has recognized this point and has undertaken to learn the lessons of industrial arts which

Europe and America have learned by centuries of experience in their development. The people of the western part of our own country and the other nations of the American continents have reached the stage of production of crude materials for the use of those who know how to utilize them; and the materials which are made from them are in part returned to the sections which produced the raw material. It is true that this is in a measure the result of sparseness of population, but only partly so. The southern states are rapidly emerging from this stage, and the west will find this its next step of progress.

When this stage is reached, population increases more rapidly, and the demand for materials increases. Our eastern states have reached the stage where nearly all economic minerals have a market value, and it is for this reason that these states hold so high a rank in mineral production; for the region is not rich in mineral resources, and only coal, iron, petroleum, building-stones, and minor substances are of importance. The west is the great mineral region of the country, and, indeed, of the world, but its resources are only partly developed. Iron, coal, building-stones, petroleum, salt, gypsum, and many minor substances are practically not produced in that section, although all of these are abundant. When this region is fully developed, it is doubtful if there will be any necessity of looking beyond the confines of the nation for more than a very few mineral products. Even at present the number of minerals which this country finds it necessary to import is small, and not only do we supply our own needs, but we export more than we import of most mineral products. Our *total* mineral exports are considerably in excess of the imports.

The rank of the nation in metallic products is given at the close of Part II.; but the statistics for non-metallic minerals are less valuable, since many of them are produced for local consumption rather than for exportation. In the production of petroleum, natural gas, and phosphates this country holds first rank, and it is doubtful if any nation has a greater production of building-stone. The rank of the country in the production of coal is second, and of salt third, among the nations of the world.

The following table shows the value of the mineral production for materials whose total value, in 1892, exceeded \$1,000,000:—

VALUE OF MINERAL PRODUCTS OF THE UNITED STATES.¹

PRODUCTS	1880.	1885.	1890.	1892.
Pig iron (N. Y.)	\$101,166,500	\$64,712,400	\$151,200,410	\$136,806,915
Bituminous coal	59,123,340	84,205,009	108,708,000	122,019,610
Anthracite coal	38,680,250	76,698,000	66,395,772	74,624,614
Silver (coining value)	39,200,000	51,600,000	70,485,714	83,909,210
Building-stone	18,356,055	19,000,000	47,000,000	45,000,000
Lime	19,000,000	20,000,000	35,000,000	38,500,000
Copper (N. Y. value)	11,491,200	18,292,999	30,930,800	37,850,000
Gold (coining value)	36,000,000	31,801,000	32,845,000	3,000,000
Petroleum	24,183,233	19,198,243	35,365,105	229,128
Lead (N. Y. value)	9,782,500	10,169,131	14,266,703	17,917,000
Natural gas . . . . .	.. .	4,857,200	18,742,725	18,000,000
Zinc (N. Y. value)	2,277,492	3,539,856	7,474,962	7,703,580
Cement	1,852,707	3,192,500	5,000,000	6,586,098
Salt	4,829,566	4,825,345	4,752,286	5,879,222
Mineral waters	500,000	1,312,845	2,600,750	3,000,000
Phosphate rock	1,123,823	2,846,064	3,213,795	2,361,219
Limestone for iron flux	3,800,000	1,618,478	2,760,811	2,097,600
Zinc-white	763,738	1,050,000	1,600,000	1,200,000
Mercury (San Francisco value)	1,797,780	979,189	1,203,615	1,119,720
Potter's clay	200,457	275,000	756,000	1,000,000

¹ Extracted from Rothwell's *Mineral Industry*, 1892, pp. 4-9.

As will be seen, there has been a considerable change in the rank of importance of the various industries since 1880.

The following table shows the total value of the mineral products of the country at intervals during the past thirteen years. This is exclusive of brick clays and some minor products which are not considered in this treatise.

TOTAL VALUE OF THE MINERAL PRODUCTS OF THE
UNITED STATES

YEAR.	METALLIC PRODUCTS.	NON-METALLIC PRODUCTS	TOTAL.
1880	\$201,283,094	\$165,440,966	\$366,724,060
1882	219,860,518	223,408,023	443,268,541
1884 . .	186,468,162	212,697,759	399,165,921
1886 .	215,658,334	247,208,210	462,866,544
1888 .	256,623,933	299,988,780	556,612,713
1890	308,641,957	337,696,669	646,338,626
1892 .	318,638,593	350,950,283	669,597,879

For the ten years ending 1889, the total mineral product of the United States amounted to \$4,627,343,630, of which less than one-half, or \$2,165,000,310 worth, were metallic products. In the above table it will be noticed that, while there has been a marked increase in the output of both metallic and non-metallic products, the most striking increase has been in the last-named group; and this will probably be more marked in the next decade.

The following table, prepared from materials in the Eleventh Census, shows the value of the mineral industries in the fourteen states which had an output of over \$10,000,000

in 1889. In the case of each state the principal mineral products are given in the order of their importance, based upon their value, but the products of minor importance are not listed although they are included in the total valuation. Thus in Pennsylvania the most important product is coal, the second petroleum, the third natural gas, etc. For each industry the rank which the state holds, in comparison with the other states, is also given in figures:—

MINERAL PRODUCTION OF LEADING STATES, 1889.

STATES.	VALUE.	MOST IMPORTANT MINERAL PRODUCTS.
Pennsylvania .	\$150,876,619	¹ Coal, ¹ petroleum, ¹ natural gas, ¹ stone, ³ iron ore.
Michigan . .	70,880,524	¹ Iron ore, ² copper, ¹ salt.
Colorado . .	41,126,610	¹ Silver, ² gold, ⁷ coal, ¹ lead, ¹² stone.
Montana . .	33,737,775	¹ Copper, ² silver, ⁴ gold.
Ohio	24,653,430	³ Coal, ² stone, ² petroleum, ³ natural gas.
New York . .	24,165,206	³ Stone, ¹ cement, ² iron ore, ² salt.
California . .	19,699,354	² Gold, ⁹ stone, ⁸ silver, ¹ mercury.
Illinois . . .	17,110,317	² Coal, ⁸ stone.
Missouri . .	15,931,575	⁸ Coal, ⁷ stone, ¹ zinc ore, ² lead.
Utah	11,681,019	³ Silver, ³ lead.
Minnesota . .	11,542,138	⁴ Iron ore, ¹⁵ stone.
Iowa	10,267,068	⁴ Coal.
Wisconsin . .	10,183,861	⁵ Iron ore, ¹³ stone.
Nevada . . .	10,143,878	⁴ Silver, ³ gold.

In 1889, of the total output of the country, which amounted to \$587,230,662, \$386,616,004 worth came from

¹ Including the New York output.

states east of the Mississippi, and \$252,083,744 worth, or nearly one-half of the total, came from those states east of the Mississippi which are partly in the Appalachians or which border the Atlantic. This is not so strikingly shown in the above table as it would have been had the states of minor importance (with an output of less than \$10,000,000) been included in the table.

The value of the imports and exports of the leading products is shown in the following table. Aside from these, the exports and imports amount to only a few million dollars annually.

EXPORTS AND IMPORTS OF MINERAL PRODUCTS, 1891.

MINERALS	EXPORTS.	IMPORTS.
Gold coin and bullion	\$79,086,581	\$44,970,110
Silver coin and bullion	27,692,879	18,192,750
Silver ore.	1,592,931	9,724,716
Petroleum	46,174,835	...
Iron, and steel, and their products . .	30,736,442	41,983,626
Tin and terne plate . . . . .	....	25,900,305
Block tin . . . . .	..	8,091,363
Copper	15,703,543	1,665,729
Precious stones . . . . .	...	12,745,435
Coal	3,000,000 ¹	1,800,000 ¹
Cement	130,371	4,411,330
Lead	173,887	2,867,633
Sulphur . . . . .	....	2,675,192
Total	\$204,291,469	\$175,028,180

In this table some manufactured articles are also included. If manufactured tin and the precious stones were omitted, our exports would greatly exceed our imports of mineral products.

¹ Estimated.

APPENDIX.



LITERATURE OF ECONOMIC GEOLOGY.

THIS list does not pretend to be a bibliography, nor is there even an attempt to refer to all of the many valuable general treatises upon the various aspects of economic geology. With the exception of works upon mining methods and metallurgy, these references are usually to works with which the author is personally familiar. For special descriptions of localities and individual economic products of this country, the files of the *American Journal of Science* and the *Engineering and Mining Journal* are of particular value, and in these there are many hundred articles of this nature. Similar sources in other countries may be resorted to for accounts of the mineral products abroad; and there, as well as in this country, such descriptions are also found scattered through the geological literature. There is no complete bibliography of the subject.¹

The national geological survey reports of the various countries all contain something of economic geology, and such descriptions usually possess great scientific as well as practical value. In the United States very important de-

¹ Since the above was written an extremely valuable treatise, entitled *Ore Deposits of the United States*, by J. F. Kemp, has been published, and one of the most important parts of the work is its very complete and extensive bibliography.

scriptions of the local mineral resources are found in the various state geological survey reports. Nearly every state in the Union has at one time or another supported a geological survey, and at present many states still have such surveys. In these, full description of the local economic geology will be found. Thus the Pennsylvania reports contain very complete descriptions and statistics concerning the coal, oil, gas, and iron industries of the state, the Ohio reports contain the same with reference to that state; the New Jersey geological survey publishes valuable information concerning the clays and iron mines; and many other states publish similar reports. These surveys, when in their best development and when properly managed, keep in advance of the development of the state, and show where valuable deposits exist and how they may be obtained. Thus the clay industry of New Jersey is the direct outcome of the work of the geological survey, the bauxite deposits of Arkansas were discovered by the survey of that state, and the oil and coal industries of several states owe much to the work of the state geologists and their assistants. Usually the publications of the surveys merely describe the local deposits; but one state, Arkansas, has gone farther than this and treated the subject in hand from a broader standpoint. Thus this state publishes monographs upon manganese and novaculites, which not only describe the local deposits, but show the position of these products in general and the probable future of the local industries. This is vastly more valuable than the mere record of local observations and of local development.

In the following list of books of reference, individual mention of the special articles in the magazines and the

geological reports is not made, excepting in exceptional cases where the material is of unusual value. Nor is especial effort made to include European works excepting such English and a few continental treatises as are of general interest.

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DANA, *System of Mineralogy*, 1892.

DANA, *Text-Book of Mineralogy*.

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BAUERMAN, *Descriptive Mineralogy*.

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BRUSH, *Determinative Mineralogy and Blowpipe*.

NASON, *Manual of Qualitative Blowpipe Analysis*.

WILLIAMS, *Crystallography*.

ROSENBUSCH, *Microscopical Physiography of the Rock-Making Minerals*
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ROSENBUSCH, *Mikroskopische Physiographie der Massigen Gesteine*.

RUTLEY, *The Study of Rocks*.

VON COTTA, *Rocks Classified and Described* (translated by Lawrence).

LE CONTE, *Elements of Geology*.

DANA, *Manual of Geology*.

PRESTWICH, *Physical and Chemical Geology*.

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WHITNEY, *Metallic Wealth of the United States*.

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 PAGI, *Economic Geology*.
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 LE CONTE, *Genesis of Metalliferous Veins* (*American Journal of Science*, 1883, Vol. XXVI, pp. 1-19).
 RAYMOND, *Mining Statistics* for 1870, p. 448.
 KEMP, *The Filling of Mineral Veins* (*Columbia School of Mines' Quarterly*, No. 1, XIII).
 WADSWORTH, *State Board of Geological Survey* for 1891-92, p. 144.

WORKS UPON SPECIAL SUBJECTS.

IRON.

- PUMPFLLY, Tenth Census, Vol. XV, pp. 1-601.
 Eleventh Census volume on *Mineral Industries*.
 PUMPFLLY, *Geological Survey of Missouri*, Report for 1872, Part I.
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- IRVING AND VAN HISE, *The Penokee Iron-bearing Series of Michigan and Wisconsin*, Tenth Annual Report U.S. Geol. Survey, pp. 347-458.
- Summary Final Report, Second Geol. Survey of Pennsylvania, Vols. I. and II., (also forthcoming volumes). Also scattered reports in Pennsylvania survey publications.
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- WHITNEY, *The Auriferous Gravels*.
- SMYTH, *The Gold Fields of Victoria*.
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ERRATA

On p 152, twelfth line from bottom of page, for "his" read "this "

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